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Contents

The Effect on Present Soil Reaction of Long-Continued Applications of Equivalent Amounts of High Calcium and High Magnesium Limes. PAUL S. BURGESS 169

The Relation of Moisture and Available Nitrogen to the Yield and Protein Content of Wheat. RAY E. NEIDIG AND ROBERT S. SNYDER 173

Further Studies on Soil Profiles. M. M. McCOOL AND A. G. WEIDEMANN. 181

Action of Stable Manure in the Decomposition of Cellulose in Tilled Soil. CHR. BARTHEL AND N. BENGTSSON 185

Residual Effects of Forty Years Continuous Manurial Treatments. I. Effect of Lime on Decomposition of Soil Organic Matter. J. W. WHITE AND F. J. HOLBEN 201

Nitrification in Some South African Soils: Part II. THOMAS D. HALL 219

Alkali Soil Investigations: IV. Chemical and Biological Effects of Treatments. J. S. JOFFE AND H. C. McLEAN 237

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THE EFFECT ON PRESENT SOIL REACTION OF LONG-CONTINUED APPLICATIONS OF EQUIVALENT AMOUNTS OF HIGH-CALCIUM AND HIGH-MAGNESIUM LIMES[1]

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Rhode Island Agricultural Experiment Station

Received for publication July 16, 1924

For more than thirty years the Rhode Island Agricultural Experiment Station has been studying the effects of different forms of lime on plants and soils for the purpose of ascertaining the best and most economical compounds to use, the optimum amounts to apply, and the proper degrees of fineness of the several materials, when present and future availability conditions are considered. While much has been written in past years on the physical, chemical and biological effects of liming soils, little data are extant on the *comparative* effects of periodic, equivalent applications of basic calcium and magnesium compounds on the hydrogen-ion concentrations of cropped field soils over long periods. From the work which has been reported it appears that such applications are thought eventually to produce approximately identical soil-reaction results, the choice of the best material to use being largely an economic matter.

Fifteen years ago the field experiment which furnished the material for this brief paper was begun. Its object was to compare the effects of the continued applications of high-calcium and high-magnesium limes, when used in chemically equivalent quantities (equal neutralizing basis) upon the resulting chemical composition of the soil and also upon plant behavior. The details of the experiment here discussed have been published recently by Hartwell (3) and by Mather (5), the former giving the agronomical data (crop yields), while the latter presents the chemical work performed from time to time upon the soils of the several plats. The reader is referred to these publications for more complete information regarding the history, system of cropping, yields and chemical soil studies. It is sufficient to state here that the same basal fertilizers

[1] Contribution 309 of the Rhode Island Agricultural Experiment Station.

have been used throughout, and uniform crops have been grown on all the plats. The lime applications per acre have been as follows:

PLAT	KIND OF LIME USED*	1909	1914	1916	1921	TOTAL †
		lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*
74N	High-calcium hydrate	4,511	2,262	3,096	2,250	12,119
76N	High-magnesium limestone	6,000	2,820	4,500	2,805	16,125
78N	High-calcium limestone	6,000	3,000	4,348	3,435	16,783
80N	High-magnesium hydrate	3,750	1,819	2,676	1,830	10,075
82N	None	0	0	0	0	0

* Applied on an equal neutralizing basis as determined in the laboratory by standard methods. The limestones were in all cases very finely ground (approximately two-thirds passing a 100-mesh sieve). For the complete analysis of these limes, see reference no. 3 p. 4.

† The equivalent of 9225 pounds of CaO per acre has been applied to each plat.

Prior to the second lime applications, in the spring of 1914, soil samples were taken from each plat and lime-requirement determinations made by the Jones method. The limed plats all showed a requirement of approximately 3,000 pounds of CaO per acre, while the check required 5,000 pounds. Subsequent to this work, no determinations for acidity were made in these soils until 1920, when the author collected a series of samples during the fall and electrometrically determined hydrogen-ion concentrations. During 1921 four more series of samples were taken and similar determinations made.[1] One series of samples also was taken in the early summer of 1922, another in 1923, and two early in 1924. All the data secured appear in table 1.

Before discussing these results, certain "lime-requirement" (calcium absorption) data also will be presented. Exactly 50 gm. of air-dry soil from each of the four samplings taken during 1921 were thoroughly mixed to form a representative sample of each of the five plats for that season, and lime-requirement determinations were made by the Jones modified method (1). Similar determinations also were made on the samples taken in 1924. The results appear in table 2.

The data in tables 1 and 2 indicate that, although added in chemically equivalent quantities, there have been decided differences in the neutralizing powers of the several basic materials employed. This is clearly shown both by the hydrogen-ion concentration determinations and by the lime-requirement tests which indicate the same comparative relationships in all cases. The high-magnesium hydrate has been most efficient as a soil neutralizer, followed by the high-calcium hydrate, the finely ground, high-magnesium limestone and the finely ground, high-calcium limestone in the order named, although there is little difference between the two limestones.

[1] The plats were limed in the autumn after the 1921 soil samples were taken.

By referring to the specific acidities (2, footnote, table 4), as listed in the last column of table 1, it will be seen that the hydrogen-ion concentrations in the soils of the two ground limestone plats are twice as great as in the high-calcium hydrate plat soil, and approximately three times as great as in the high-magnesium hydrate plat soil. The relative standing of these compounds may be explained in part by the differences in the solubilities of the carbonates and bicarbonates resulting from the carbonation of the hydrates in the soil solutions, and in part by the relative surfaces exposed to solution by the vari-

TABLE 1

Hydrogen-ion determinations of field soils treated with equivalent quantities of high-calcium and high-magnesium limes

PLAT	FORM OF LIME	1920	1921				1922	1923	1924		AVERAGE	SPECIFIC ACIDITY
		November	May	July	August	September	July	July	April	July		
		pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	
74N	High-calcium hydrate	7.2	6.6	6.3	6.3	6.3	7.0	6.5	5.8	5.8	6.42	4.0
76N	High-magnesium limestone	7.2	6.3	6.1	6.1	6.2	6.0	6.0	5.6	5.7	6.13	8.0
78N	High-calcium limestone	6.6	6.4	6.2	6.3	6.4	5.9	5.8	5.6	5.7	6.10	8.0
80N	High-magnesium hydrate	7.4	7.1	6.4	6.6	6.7	6.8	6.7	5.9	5.9	6.61	2.5
82N	None	5.2	4.9	4.7	4.9	4.9	4.5	4.5	4.5	4.5	4.73	200.0

TABLE 2

Lime-requirement (Jones method) in pounds per acre on field soils treated with equivalent quantities of high-calcium and high-magnesium limes

Plat	74N	76N	78N	80N	82N
Treatment	High-calcium hydrate	High-magnesium limestone	High-calcium limestone	High-magnesium hydrate	No lime
Sampled 1921	1,530	1,800	1,530	1,440	3,690
Sampled 1924	1,580	2,120	1,670	1,400	4,400
Total crops removed during last 7 years (tons)	47.0	48.0	47.0	48.6	29.1

ous-sized particles, for, while the carbonates were both finely ground, the hydrates were impalpable powders of extreme fineness. It hardly seems probable that the time element could be an important factor here. Fifteen years have elapsed since the first lime applications were made, while the last additions were made three years ago. This should have given sufficient time for the attainment of a condition of approximate equilibrium between the soil and the liming materials.

An interesting sidelight on this very point is presented by the yields of several crops, known to be especially sensitive to acid-soil conditions, when grown regularly each year subsequent to an equivalent application of hydrated lime

and ground limestone of different degrees of fineness (4). The crops referred to are alfalfa, beets and barley. During the first three years, the yields were all about the same following initial applications of either hydrated lime or finely ground limestone (80-mesh), but during the next two years the yields were decidedly better where the hydrated product had been used. It thus appears that *finely ground* limestones are less permanent in their effects on acid soils than are the hydrated limes. This is probably largely due to leaching.

It is also of interest that the plat receiving the high-magnesium hydrate has, during the past seven or eight years, produced somewhat larger crops than any of the other limed plats.

From the data here presented, it appears that measurable differences in the ability to neutralize soil acidity are shown between the hydrates and carbonates of high-calcium and high-magnesium limes when applied to field soils in chemically equivalent quantities over long periods of time, and that such differences, to a slight extent, are reflected in crop yields.

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THE RELATION OF MOISTURE AND AVAILABLE NITROGEN TO THE YIELD AND PROTEIN CONTENT OF WHEAT[1]

RAY E. NEIDIG AND ROBERT S. SNYDER

Idaho-Agricultural Experiment Station

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A previous investigation (1) showed the effect of available nitrogen in the elaboration of the wheat kernel under both greenhouse and field conditions. The results indicated that the chief factor influencing the yield and protein content of wheat was moisture, when sufficient available nitrogen was present. For the purpose of definitely correlating the effect of different percentages of moisture on the protein content and yield of wheat both with and without an excess of available nitrogen, the following experiment was planned.

Thirty-nine pots were used. Treatments were made in triplicate. Each pot contained the equivalent of 26.5 pounds of oven-dried soil. The soil was obtained from the B_2 plot previously described (1). It is a soil which has been cropped continuously to wheat for 9 years. To the entire series of pots equal amounts of sodium acid phosphate, potassium chloride and lime were added. Palouse Bluestem wheat was planted on May 10, 1923. After a few days' growth the plants were thinned to seven in each pot. An explanation of the various moisture and nitrogen treatments follows.

A number of pots were kept at 25 per cent moisture content. The moisture equivalent[2] was found to be 25, which was assumed to be somewhere near the optimum moisture content; others were kept at 20 and 15 per cent throughout the entire life cycle of the wheat plant. The moisture content of all pots was kept at these different percentages by carefully weighing the pots and adding the required amount of water at frequent intervals. A series was included in which the moisture content of the soil was kept at 25 per cent until the fruiting period, then reduced to 15 per cent for the remainder of the growth and ripening period of the wheat plant. Another series was included which was treated just the reverse; that is, the moisture of the soil was kept at 15 per cent until the beginning of the fruiting period, then raised to 25 per cent for the fruiting and ripening period. To all of these series nitrogen was added in two different systems of treatments; one, the entire amount added at the time of planting; the other, fractional amounts added cumulatively, or at five different intervals in the life cycle of the wheat plant until the total quantity added equalled the entire addition made at the time of planting. An excess of nitrogen was desired, hence nitrogen at the rate of 200 pounds per acre in the form of sodium nitrate was added in both methods of applications. Check series of the soils also were included which did not receive nitrate additions but which had the moisture percentages varied.

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[1] Published with permission of the Director of the Idaho Experiment Station.

[2] Determined by Prof. G. R. McDole, Soil Technologist of the Idaho State Experiment Station.

The results given in table 1 plainly show the effect of the three different moisture percentages on the plants grown without nitrate fertilizer. At a moisture content of 25 per cent, the yield and the weight of 100 kernels were greater, while the protein content was lower than at 20 or 15 per cent. Changes of moisture are noted directly in the yield of wheat and weight per 100 kernels. The shriveled condition of the kernels from pots 19–21 and 28–30 partly accounts for the increased protein content of wheat.

TABLE 1

Yield and protein content of wheat as affected by different treatments of moisture and available nitrogen

POT NUMBER	$NaNO_3$ ADDED PER ACRE PER TREATMENT	MOISTURE	NUMBER OF HEADS	TOTAL YIELD OF WHEAT	TOTAL YIELD OF STRAW	RATIO OF GRAIN TO STRAW	WEIGHT OF 100 KERNELS	PROTEIN CONTENT
	lbs.	*per cent*		*gm.*	*gm.*		*gm.*	*per cent*
4–6	None	25	8	4.57	8.5	1–1.86	3.21	16.82
19–21	None	20	7	2.83	7.0	1–2.47	2.52	17.48
28–30	None	15	7	2.97	6.3	1–2.12	2.83	18.01
	Sodium nitrate added May 10, date of planting							
1–3	200	25	20	13.63	27.6	1–2.03	3.35	17.44
16–18	200	20	18	10.47	20.4	1–1.91	3.49	17.91
25–27	200	15	16	9.80	16.4	1–1.68	3.28	18.30
	Sodium nitrate added May 10, June 4, June 29, July 24, and August 18							
7–9	40	25	19	14.40	25.9	1–1.80	3.57	17.67
22–24	40	20	20	12.23	21.8	1–1.78	3.47	18.97
31–33	40	15	16	9.40	17.0	1–1.81	3.17	19.77
	Soil moisture changed at beginning of fruiting period; nitrate added May 10							
13–15	200	25 to 15	21	11.00	25.9	1–2.35	3.51	19.35
37–39	200	15 to 25	22	13.07	25.4	1–1.94	3.02	17.06
	Soil moisture changed at beginning of fruiting period; nitrate added May 10, June 4, June 29, July 24, and August 18							
10–12	40	25 to 15	20	12.83	23.8	1–1.85	3.57	19.55
34–36	40	15 to 25	19	12.90	24.4	1–1.89	3.18	17.76

When the additions of nitrogen were made at the time of planting, the effect of the three different moisture percentages on yield was in favor of the higher moisture content. This series has the largest number of heads, the greatest yield of both wheat and straw, and the lowest protein content. The results for the other two series, 20 and 15 per cent, follow in decreasing order for number of heads, yield of wheat and straw, and in increasing order for the protein content. In all three series, plump wheat kernels were produced. The kernels in the 15 per cent series weighed only slightly less than the others.

When the series receiving the entire addition of nitrate at the time of planting are compared with their respective check soils, the effect of available nitrogen on the yield and protein content is shown to be very marked. The effect of cumulative additions of an equivalent amount of nitrate, made at five stages during the growth of the wheat plant, to soils kept at varying moisture percentages, (25, 20, and 15 per cent) was consistent with the data just discussed. The yields of wheat and straw follow in order of the moisture content, the 25 per cent moisture content showing the heaviest yields. The weight per 100 kernels also is found to be in the same order. The greater amount of protein, however, is found in the 15 per cent moisture series, and it decreases in the remaining two moisture series in reverse order of the yield and the weight per 100 kernels. Here again is seen the effect of moisture, on the yield and protein content of wheat even in the presence of an excess of available nitrogen; also the effect of available nitrogen in increasing the protein content of wheat over that of wheat grown on the check soils without nitrate additions, for all three moisture series.

In part 3 of table 1 are given the data on the effect of adding the entire nitrate additions at the time of planting to soils which are kept at 25 and 15 per cent moisture until the beginning of the fruiting period when the moisture content in one series was lowered to 15 per cent and in the other, raised to 25 per cent. This was done to note the effect of a high and low moisture plane, at different periods of growth of the wheat plant, on the yield and protein content of wheat.

The series at 25 per cent moisture content up to the fruiting period and 15 per cent thereafter, yielded slightly less of both grain and straw than the series at 25 per cent moisture content during the entire life cycle of the plant, but the protein content was higher. The former series corresponded more nearly to actual growing conditions in this section. In this first series, however the yield of grain is increased and the weight of 100 kernels and the percentage of protein both decreased in comparison with the series to which only 15 per cent moisture was added up to the fruiting period and then increased to 25 per cent for the ripening period of the wheat plant. This series developed an unnatural condition which would seldom occur under field conditions; that is, when the moisture was increased to 25 per cent at the beginning of the fruiting period, the plants immediately began to throw out new shoots and these developed and matured very slowly. When the plants were harvested, a considerable number of immature, shriveled heads were present. This is shown in the lower weight of 100 kernels and the lower protein content. Under field conditions, the results would have been similar with excessive moisture during the fruiting period.

Practically the same conclusions can be drawn from the results given in part 4 of table 1. The treatments differ from those in part 3 only in one particular; that is, the nitrate treatments were made in five cumulative applications rather than the entire amounts at the time of planting. Here again wheat grown on

pots receiving 25 per cent moisture for the entire period gave a larger yield and contained less protein than that from soil with a moisture content of 25 per cent reduced to 15 per cent.

Pots 37–39, and 34–36 showed similar yields to pots 13–15 and 10–12, the protein content and weight per 100 kernels were considerably lower, for the same reason as stated above.

A comparison of the effect of varying amounts of moisture, on wheat grown with nitrate added in entirety at the time of planting, and in five cumulative additions, is more easily seen when table 1 is studied.

The effect of moisture on the wheat plant is easily compared on the check soil, without nitrate additions. In part 2, the two systems of nitrate additions are compared at the three different moisture contents. Here it is seen that for the series of soils kept at 25 per cent moisture, nitrate added in five cumulative additions produces wheat which is slightly higher in yield, weight per 100 kernels, and protein content than when all the nitrate is added at once at the time of planting. The yield and protein content also are higher with the cumulative additions for the 20 per cent series, with an approximately equal yield and a higher protein content in the 15 per cent series, the respective series to which all the nitrate was added at the time of planting. These differences are small, as would be expected, because of the initial large addition of available nitrogen. Under average field conditions much wider variations might be expected because the available nitrogen is not present in such large quantities in the soil.

Changing the moisture content at the fruiting period from optimum to low, results in a lower yield, but a higher protein content than when the optimum moisture is continued throughout the entire life cycle of the plant. In this same experiment, the higher protein content and yield are found in the wheat grown on soils receiving the cumulative additions, rather than all the nitrate at once. However, both treatments yield wheat of large kernels and high protein content.

When the moisture content is reversed, that is the soil maintained at 15 per cent until the fruiting period, then raised to 25 per cent, a lower yield occurs than when the soil is kept at the optimum moisture content of 25 per cent. Comparing the above moisture content with the reverse treatment, that is, 25 per cent up to the fruiting period, then reduced to 15 per cent, only a slight difference is noted in the total yield, while a difference of approximately 2 per cent in the protein content is noted in favor of the low over the high moisture content during the ripening period. Changing low to high at fruiting time causes more shoots to grow, resulting in an immature wheat kernel. While the yield may be slightly greater, the kernels are smaller and the quality of wheat poorer. This particular result would scarcely be realized under field conditions, because the immature heads would never ripen in sufficient time to affect the yield.

By way of summary it may be concluded from the results given here and elsewhere (1) that in the presence of an abundance of available nitrogen,

moisture plays an important rôle in the yield and protein content of wheat. When the available nitrogen is sufficient, as in this experiment, for a maximum growth of the plant, both yield and protein will be influenced, but yield more than protein.

It makes little difference, under optimum moisture conditions, whether the 200 pounds of nitrate is added at the time of planting or throughout the life cycle of the plant, provided sufficient is applied at planting time to insure the presence of a liberal quantity in the soil during the fruiting and ripening period.

TABLE 2

Effect of variations in rainfall on wheat yields under field conditions

	1914	1917		1922		1923	
	Acre yield	Acre yield	Protein content	Acre yield	Protein content	Acre yield	Protein content
	bu.	*bu.*	*per cent*	*bu.*	*per cent.*	*bu.*	*per cent*
B_2 continuous	38.6	5.7	12.29	11.1	14.44	38.8	10.43
D_8 wheat	38.2	10.07	12.14	11.8	13.19	43.0	13.26
E_{10} plots	30.7	8.20	13.17	16.6	13.45	42.2	10.21
Average	35.82	7.99	12.53	13.17	13.67	41.3	11.30

Monthly rainfall

	1914	1917	1922	1923
	inches	*inches*	*inches*	*inches*
January	3.58	2.86	2.04	3.93
February	1.95	1.76	1.49	1.71
March	0.76	1.13	2.50	1.56
April	1.76	3.63	1.47	2.52
May	2.00	1.81	0.47	1.44
June	1.36	0.72	0.22	3.37
July	0.70	0.05	0.00	1.19
August	0.00	0.00	1.52	0.26

Fall, 1916—Not heavy precipitation; slightly below normal.
Fall, 1921—Normal, fairly heavy.
Fall, 1922—Slightly below normal.

Cutting down the moisture content during the fruiting period results in a smaller yield, but a considerable increase in protein content over the optimum moisture series. This condition is more nearly similar to actual field conditions.

The greatest effect of a lack of moisture on the check soil, which is low in available nitrogen, is shown on the yield. With an optimum moisture content, a greater yield is obtained than when less moisture is present. Favorable moisture conditions allow more plant-food to become available and result no doubt in better nutrition of the plant.

An example of the effect of moisture on the yield and protein content of wheat grown under field conditions is clearly shown by a comparison of a few

years' data from a rotation experiment now under way on the Agricultural Experiment Station Farm. This experiment includes three plots that have grown wheat continuously since 1914. Each year the yield of wheat and the proteins content have been determined. Government records of rainfall also have been kept. The data on rainfall, yields and protein content of wheat for the years, 1914, 1917, 1922 and 1923 are given in table 2. The protein content of the initial wheat crop grown in 1914 was not determined.

The effect of seasonal rainfall on the yield of wheat is very clearly shown when the average yields for the four years and rainfall are compared. Since the plots have been producing wheat each year since 1914, the fertility is much lower than if a rotation or fallow were practiced. In 1917 and 1922 the yields were much lower than in the first year, 7.99 bushels in 1917,[3] 13.17 bushels in 1922, and 35.82 bushels in 1914. The rainfall for the years 1917 and 1922 was below normal, especially during May, June and July. The yield for 1923, however, a very rainy year, averaged 41.3 bushels, an abundant yield in spite of the fact that these particular plots had raised ten continuous crops of wheat. The favorable distribution of moisture no doubt accounts in a large measure for these large differences, favoring bacterial activities and causing more plant food to become available.

We find that the wheat grown in 1917 and 1922 had a higher protein content than that grown in 1923. On soil low in available nitrogen, when the yield is small because of a low rainfall, the protein content is increased over that of wheat grown on the same soil with an abundance of moisture. Also the protein content is raised because of a partially shriveled condition of the wheat kernel whenever sufficient moisture is lacking during the fruiting and ripening period.

In 1923, however, with favorable moisture conditions and a high yield, the protein content was only 11.3 per cent. On a soil low in fertility, even in the presence of abundant moisture, a high yield of wheat results in a low protein content.

It is noted that the wheat plant carefully regulates the protein content, and if there is a lack of available nitrogen or moisture, yield is the first to be decreased. With both moisture and available nitrogen present in abundance throughout the life cycle of the plant, yield will be affected the greater, with protein showing an increased percentage over wheat grown on a soil low in available nitrogen. In soil poor in available nitrogen, a low moisture content also may result in a low yield, but an increase in the protein content of the kernels due to a shriveling of the grain caused by a moisture deficiency during the fruiting and ripening period.

The results of this work fully corroborate conclusions previously drawn (1).

[3] Considerable winter killing took place in this crop.

SUMMARY

1. A high moisture content in a soil containing sufficient available nitrogen for the maximum growth and development of the wheat plant, results in high-yielding wheat containing a high percentage of protein.

2. A low moisture content in the soil containing an excess of available nitrogen results in a lower yield of wheat but a higher protein content. A part of the higher protein content may be due to a shriveling of the wheat kernel.

3. A high or optimum moisture content in a soil, which has considerable nitrogen available for the wheat plant in the early periods of growth, but an insufficient amount during the fruiting and ripening periods for maximum growth, results in a high yield of wheat of low protein content.

4. A low moisture content in a soil which has sufficient nitrogen available to the wheat plant during the early stages of growth, but an insufficient amount for the fruiting and ripening periods, results in a low yield of wheat, the percentage of protein varying according to the degree to which the wheat is shriveled from moisture deficiency.

5. Under field conditions a high moisture content, such as sometimes occurs during seasons of abundant rainfall, properly distributed during the growing period, on average soil will produce a high yielding wheat with a low protein content. A highly fertile soil under the same conditions also produces a high yield of wheat but may show an increase in protein content if sufficient available nitrogen is present during the entire life cycle of the plant. If the protein is not increased, the effect of the increased fertility of the soil will usually be reflected in a higher yield of wheat. A soil cropped continuously to wheat will produce more in a season of abundant rainfall than in a dry season, especially if rains are lacking during the fruiting and ripening periods. High yields and good quality of wheat require proper moisture conditions and a fertile soil.

REFERENCE

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FURTHER STUDIES ON SOIL PROFILES[1]

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It was shown in a former contribution (2) that the soils of Michigan may be logically placed into two groups designated simply as northern and southern. Reference was made also to a transitional group. Further mention of these groups may be found in another publication (1). Furthermore, the desirability of studying soil profiles was emphasized. If samples of soil are taken to arbitrary depths for laboratory studies or field investigations, erroneous results may be obtained. That is to say, the roots of the plants may, and doubtless do, come into contact with horizons that vary markedly in their nature; and if two or more of these horizons are mixed in sampling, the true environmental conditions of the plant-root system may not be brought to light. It may be cited, for example, that the third or brown horizon of the northern profile may exhibit very different properties if portions of the second or fourth horizon are mixed with it in the sampling.

In order to bring out differences that may occur chiefly with the colloidality of the various horizons in several profiles, additional investigations have been conducted. The heat-of-wetting method appeared to be valuable in bringing out some of these differences. These studies were made in the usual way, with the use of water, nitrobenzole, 95 per cent alcohol and absolute alcohol. The results are summarized in table 1.

In comparison with this work on the mineral soil profile some similar work was done on muck profiles, the results of which are given in table 2. Inasmuch as the ash content of the various horizons of organic deposits varies considerably and has such a tremendous influence on the other properties, the ash content of these horizons also was determined.

The data in table 1 show strikingly the difference in activity of the humus horizon on being treated with the different liquids used. It has been observed that the heat of wetting of organic soils with water is many times greater than that of mineral soils. The data here recorded show the heat of wetting of the humus horizon with water to be much greater than that of the other horizons. This is not true of the other liquids used, with the possible exception of 95 per cent alcohol.

[1] Published by permission of the Director of the Experiment Station.

TABLE 1

Heat produced per 50 gm. of soil with different liquids

SOIL TYPE	HORIZON	WATER	NITRO-BENZOLE	95 PER CENT ALCOHOL	ABSOLUTE ALCOHOL
		calories	*calories*	*calories*	*calories*
	Soils of southern group				
Coloma (Southern)	1. Virgin humus soil	109.32	34.88	67.23	32.30
	2. Yellow concentrated horizon	49.96	27.74	29.73	16.39
	3. Basal soil, sandy	20.53	22.17	22.28	14.26
	4. Parent material, sand	17.29	12.43	7.41	5.69
Bellefontaine	1. Virgin mold and humus, 0 to 3 inches	179.42	52.06	111.96	
	2. Pale yellowish sand, leached	65.52	54.33	56.00	38.02
	3. Reddish horizon, concentrated	121.94	90.89	129.00	113.93
	4. Basal layer	123.91	96.36	127.20	106.52
Waukesha	1. Dark brown humus soil, 0 to 10 inches	153.64	48.32	112.50	32.45
	2. Yellowish loam	113.05	55.90	90.56	66.17
	3. Reddish yellow tight clay	135.36	93.81	142.75	122.92
	4. Basal soil, gravelly	40.71	45.09	42.24	32.11
Napanee	1. Humus soil	235.38	48.67	147.80	38.47
	2. Pale, yellowish gray silt	105.81	60.15	86.09	59.08
	3. Brownish mottled upper portion horizon of clay concentration	114.83	93.67	109.22	93.56
	4. Lower portion of clay concentration	142.98	116.60	146.10	109.10
	5. Parent till clay	104.46	89.11	97.10	96.87
	Soils of northern and transitional group				
Coloma (transitional)	1. Virgin forest soil	79.28	34.61	44.70	14.28
	2. Gray leached sand	21.62	15.21	11.86	5.69
	3. Yellow concentrated layer	34.40	31.18	28.23	18.25
	4. Basal soil, sand	28.03	27.70	22.27	14.24
	5. Substratum, sand	11.43	13.12	11.11	5.58
Emmet	2. Gray leached sand	12.73	12.44	12.61	4.26
	3. Brown horizon, loamy sand	63.97	37.54	44.71	19.28
	4. Basal soil, sand 20 to 36 inches	21.62	16.60	11.86	10.67
	5. Substratum sand	13.98	14.50	10.38	3.55
Mancelona	Virgin forest soil 0 to 30 inches	227.10	36.24	104.40	
	Gray leached sand	43.41	27.74	28.26	7.27
	Brown loamy sand	48.55	41.65	37.21	21.69
	Basal soil loamy sand	39.55	36.67	31.99	
	Gravelly parent material	52.31	39.48	44.63	27.17

Note: The specific heats of the liquids were taken as follows:

Water	1.00
Nitrobenzole	0.35
Absolute alcohol	0.56
95 per cent alcohol	0.58

In the case of some of these profiles the heat of wetting of the humus horizon with nitrobenzole and absolute alcohol is slightly greater than that of the other horizons but in a few cases it is actually lower. There is not very much difference between the heat of wetting of the mineral, or lower, horizons with the different liquids. In the case of the heavier types of soil the heat of wetting of the lower horizons with nitrobenzole and absolute alcohol is remarkably high. The reddish brown horizon or the one of greatest concentration of colloids, either mineral or organic, shows considerably greater activity with all liquids used than do the coarser-textured horizons adjacent to it.

TABLE 2

Heat produced per 25 gm. of muck with different liquids

NAME	HORIZON	ASH	WATER	NITRO-BENZOLE	ABSOLUTE ALCOHOL
		per cent	*calories*	*calories*	*calories*
Shaw's Muck	0 to 6 inches well decomposed	31.46	638.15	34.27	16.34
	6 to 12 inches slightly coarser, lower ash	17.95	724.10	28.99	11.51
	12 to 18 inches finely divided	10.12	690.30	28.25	18.84
	44 to 48 inches colloidal	64.91	295.95	33.26	56.36
Farm Lane	0 to 6 inches well decomposed	28.91	669.25	28.30	22.08
	6 to 12 inches slightly coarser	23.57	752.00	33.44	20.33
	24 to 36 inches somewhat fibrous	7.31	638.75	31.80	61.82
	48 to 60 inches colloidal	28.77	488.95	28.88	15.27

These differences are significant in that in a given soil profile there are horizons that react quite differently to a given liquid, and also to different liquids when brought into contact with them. Of course, when heat is evolved it must be concluded that either chemical or physical reaction, or both, have taken place. It is an expression of energy change. Thus, when horizon 1 is relatively inert to nitrobenzole or absolute alchohol and horizon 3 or 4 reacts very differently it seems logical to conlude that the nature of the colloids is strikingly different too—that is, if we assume that the colloids are responsible largely for the heat-of-wetting results. It would appear that when a given substance is used in studying colloids, for example, by absorption or heat of wetting, important differences may not be brought out. Yet it seems that the heat-of-wetting method has great possibilities in the determination of the colloidality of soils.

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ACTION OF STABLE MANURE IN THE DECOMPOSITION OF CELLULOSE IN TILLED SOIL[1]

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INTRODUCTION

It is well known that stable manure exercises a favorable influence on the decomposition of cellulose in tilled soil. A. Koch (8) tried in 1890 to demonstrate this quantitatively, but the method used was very primitive and could never be expected to gain anything like general application in work of this kind. It was only after Charpentier (5) in 1920 had worked out in this laboratory a reliable method for the quantitative estimation of cellulose in soil, that the factors affecting the decomposition of cellulose in soil also could be accurately investigated.

In 1921 Charpentier (6) published some investigations dealing with the effect of stable manure on the decomposition of cellulose in different kinds of soils of different reaction and moisture content. Stable manure was invariably observed to have a distinctly favorable effect on the decomposition of cellulose, in soils having the optimum moisture content for the action of microörganisms. The reaction has hardly any influence in this connection, for according to Charpentier's experiments, a vigorous decomposition of cellulose can take place in acid as well as alkaline soils, the addition of lime having no effect. This is of course due to the fact that the cellulose-fermenting organisms which occur plentifully in all soils, belong to widely different groups, including aerobic and anaerobic bacteria of different kinds, as well as actinomycetes and moulds. According to the reaction of the soil and its other properties, one or the other of these groups of organisms will become predominant in the decomposition of the cellulose.

As to the mode of activity of manure in this connection, there are really only two possibilities to be considered: first, the cellulose decomposing organisms in the manure may cause a more vigorous decomposition of the cellulose occurring in the soil, or, second, it may be that the nutrient substances in the

[1] This paper has been published in Swedish as a bulletin from the Central Agricultural Experiment Station at Stockholm, but because of the inaccessibility of the original to most of the workers in English speaking countries, its English translation is presented in Soil Science.—EDITOR.

manure bring about a more vigorous development of the microörganisms already present in the soil, including the cellulose splitters, thus promoting cellulose decomposition. This would amount to an indirect biological action due to the manure. Finally, a combined direct and indirect biological action might also be imagined.

Up to this time the first of these theories undoubtedly has had the most supporters. It is almost a dogma that one of the most valuable properties of stable manure is its large content of microörganisms which upon being added to the soil greatly stimulate the microbiological changes taking place. However, we may search in vain in the available literature for a really convincing proof of the direct microbial action of manure. On the other hand, several circumstances speak *against* any such action when some of the most important factors are carefully considered from a bacteriological point of view.

We are now of the opinion that the addition of cultures of certain microorganisms or mixtures thereof to the soil has no real or lasting effect on it. It appears that a certain equilibrium between the different species is established in the soil, an equilibrium which is not disturbed by an occasional inoculation with one kind of organism or another. In order to alter the microbial life of the soil it is necessary to effect changes of a different nature which will modify its physical or chemical properties, e.g., draining, working, liming or manuring. By such means the microflora may be stimulated as a whole, or certain groups of organisms may be stimulated, the result often being an increase in the fertility of the soil in question. Thus *a priori* it is not very likely that an inoculation of the soil with the microörganisms introduced with the manure can exercise a direct influence on the biological condition of the soil itself. The bulk of the microörganisms present in manure, are specifically intestinal bacteria, and we have no certain knowledge as to the ability of these organisms to develop in the soil. It is true that livestock manure contains, for example, powerful cellulose-splitting organisms, but such organisms can always be found also in the soil. Very probably the bulk of the microorganisms introduced into arable soil with stable manure die there after a short time instead of increasing the microflora. It must be remembered that the conditions in the soil differ very widely from those in the intestines, for example, with regard to temperature and aeration.

Again, if the influence of stable manure is attributed chiefly to its content of nutrient substances readily assimilable by the microörganisms already present in the soil, then it is suggested that the determining factor is the nitrogen content of the manure, especially the ammoniacal nitrogen.

Charpentier (6) carried out a short investigation comparing the effect of 2 per cent of cow manure containing 0.16 per cent of ammonia nitrogen with that of an equivalent amount of ammonium sulfate as regards ammonia nitrogen. The pots contained 1 per cent of cellulose in the form of finely cut filter paper. Two parallel pots of each kind were prepared.

The results showed the effects of the cow manure and the ammonium sulfate, respectively, to be the same, which again favors the view that the ammonia nitrogen in the manure is the deciding factor under the circumstances

TABLE 1

Influence of various ammonium salts upon cellulose decomposition in the soil

POT NUMBER	AMMONIUM SALTS ADDED PER KILOGRAM OF SOIL		2 MONTHS		4 MONTHS		6 MONTHS		8 MONTHS	
			Cellulose	Average	Cellulose	Average	Cellulose	Average	Cellulose	Average
		mgm. NH_4-N	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Ia	None	—	0.71	0.70	0.66	0.59	0.62	0.57	0.47	0.39
Ib			0.69		0.53		0.52		0.31	
IIa	$(NH_4)_2SO_4$	10.2	0.56	0.58	0.51	0.50	0.40	0.36	0.30	0.29
IIb			0.59		0.48		0.32		0.28	
IIIa	$(NH_4)_2SO_4$	20.4	0.47	0.45	0.39	0.44	0.36	0.33	0.29	0.26
IIIb			0.43		0.49		0.30		0.22	
IVa	$(NH_4)_2SO_4$	40.8	0.29	0.27	0.15	0.18	0.13	0.14	0.06	0.07
IVb			0.26		0.21		0.16		0.09	
Va	NH_4NaHPO_4	24.1	0.36	0.36	0.30	0.25	0.24	0.21	0.18	0.17
Vb			0.35		0.19		0.19		0.16	
VIa	NH_4NO_3	10.2	0.45	0.45	0.34	0.31	0.24	0.26	0.19	0.18
VIb			0.44		0.27		0.27		0.18	
VIIa	NH_4NO_3	20.4	0.27	0.27	0.18	0.21	0.16	0.17	0.10	0.11
VIIb			0.27		0.24		0.17		0.12	
VIIIa	CH_3COONH_4	20.4	0.49	0.48	0.44	0.38	0.34	0.32	0.30	0.27
VIIIb			0.46		0.32		0.30		0.24	
IXa	$(NH_4)_2CO_3$ $+2NH_4HCO_3$	20.4	0.40	0.46	0.25	0.32	0.21	0.27	0.13	0.21
IXb			0.52		0.39		0.32		0.30	

in question. This isolated trial, of course, is insufficient for the drawing of any definite conclusions.

NEW INVESTIGATIONS

If the reason for the favorable action of the stable manure on the course of the cellulose decomposition is primarily to be sought in its content of ammonia

nitrogen, then the action should naturally be the same in whatever form this material might be added to the soil, provided of course that the amounts of ammonia nitrogen in the soil samples to be compared with respect to cellulose decomposition were always the same.

In the first place, a series of experiments was instituted in which different ammonium compounds were added to the same soil (a heavy clay soil of neutral reaction from the Central Agricultural Experiment Station) to which 1 per cent of finely cut filter paper was added (Munktell's No. 10). The soil with cellulose was divided among a number of pots each holding 1 kgm. of soil, after which 20.4 mgm. of ammonia nitrogen was added to each pot in the form of different ammonium salts. This addition corresponds to the amount of ammonia nitrogen added with 1 per cent of manure containing 0.2 per cent of ammonia nitrogen. The ammonium salts used in this investigation were ammonium sulfate ($(NH_4)_2SO_4$), acid sodium ammonium phosphate ($NH_4NaHPO_4+4H_2O$), ammonium nitrate (NH_4NO_3), ammonium acetate (CH_3COONH_4), and ammonium carbonate ($(NH_4)_2CO_3+2NH_4HCO_3$).

The pots were closed with paraffined corks in the middle of which short glass tubes packed full of cotton wool were inserted. By this means the evaporation of water is reduced to a minimum while a certain amount of ventilation is obtained. The water lost by evaporation from the pots was not replaced during the experiments without the solids and cellulose being estimated in the soil. The cellulose was then recalculated with respect to soil of the original water content.

For the sake of control, quantities of the different ammonium salts corresponding to double and half the above-mentioned amount of ammonia nitrogen (20.4 mgm. per kgm. of soil) also were taken. The cellulose content of the soil in the different pots was estimated at intervals of two months during a period of 8 months, the pots being kept at room temperature.

METHOD OF ANALYSIS

The cellulose was estimated by Charpentier's method (5) with some modifications.

After the contents of the pot had been mixed, 20 gm. was weighed out in a 150-cc. Lovén flask , and the sample was set to dry for 24 hours in a thermostat at 42°C. The water was thus reduced to about 1 per cent. Then 100 cc. of Schweitzer's reagent was added by means of a Berglöf pipette with a Geissler-Miescher stopcock. By drying the sample, the dilution of the Schweitzer's reagent by the water of the soil is avoided; it is important that the reagent should have the right strength.[2]

[2] The reagent is conveniently made as follows:

To a solution of 500 gm. of crystallized copper sulfate in 25 liters of water in a large glass cylinder is added 275 cc. of ammonia of sp. gr. 0.91, with stirring, at a temperature of about 40°C. The precipitated copper hydroxide will be coarse, quickly sinking to the bottom; the supernatant salt solution is siphoned off, the precipitate is mixed with water to the original volume, and after settling, the clear liquor is siphoned again. This washing is repeated two or three times after which the precipitate is freed from the water as far as possible, transferred to a glass stoppered 12-liter flask, and dissolved in 8 liters of ammonia, sp. gr. 0.91, being shaken at intervals during 2 to 3 days, to saturation. The reagent thus prepared contains about 1.5 gm. of copper per 100 cc.

After the stopper of the Lovén flask had been fastened by a clamp (fig. 1), which was designed by E. Sandberg, the flask was fixed in a shaking machine capable of holding 10 flasks and making 60 revolutions per minute, the length of the flask being at right angles to the axis of the machine. After shaking for one hour they were allowed to stand overnight. About 60 cc. of the clear liquor was carefully decanted into a dry Lovén flask which was then closed with a rubber stopper having two holes, one for a 50-cc. pipette reaching to the bottom of the flask and the other for a short glass tube which was connected with a hand pump. The solution was slowly pumped up until the level stood somewhat over the mark, whereupon the pipette was closed, and the rubber stopper removed. Exactly 50 cc. was measured

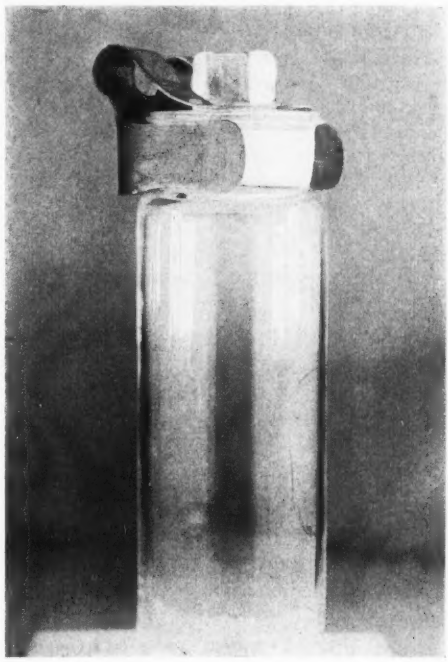

FIG. 1. LOVÉN FLASK WITH SPECIAL STOPPER USED IN THE EXPERIMENTS

off into a 300 to 400-cc. beaker, and the cellulose was precipitated by the addition of 200 cc. of 80 per cent ethyl alcohol while stirring with a glass rod. As the subsequent filtration is more rapid when the precipitate has completely settled, this operation was postponed until the following morning. According to Barthel's suggestion, the Gooch crucible recommended by Charpentier was replaced by a 35-cc. alundum crucible (of medium fine porosity) of which the wall was glazed about two-thirds of the way down from the rim. This crucible was fixed to a suction flask as usual by means of a rubber connection and a funnel tube. The solution was carefully transferred to the crucible so that the bulk of the cellulose precipitate remained in the beaker. By means of two rinsings with 35 cc. and 25 cc. of 12 per cent hydrochloric acid, respectively, the greater portion of the precipitate was removed to the crucible, whereupon the remaining particles of cellulose were detached from the beaker by means of a glass

rod tipped with a rubber tube, and transferred by means of 35 cc. of cold distilled water from a wash bottle. In these successive transferences and the subsequent washings, care was of course taken that the crucible was sucked empty after each addition. In order to get rid of a quantity of humic acids which are also dissolved in Schweitzer's reagent and later precipitated by the alcohol the crucible was filled with 2 per cent caustic potash solution. As a rule the filtrate here was first colored brown by humates, later on becoming colorless. The washing was then continued with 35 cc. of 2 per cent hydrochloric acid (as it is easier to wash a precipitate free from salt or acid than from alkali) and was concluded with 35 cc. of cold distilled water. To facilitate the drying, the cellulose was treated (without previously emptying the pump flask) with 25 cc. of 95 per cent alcohol and 25 cc. of ether in due turn. The crucible was then allowed to stand for one hour at 100°C. in a water oven, and then in a desiccator to cool. The cellulose was now in the form of a snow white shell-like film which could easily be loosened from the crucible. With the help of a little silver spoon it was transferred to a recently ignited and cooled platinum crucible, and ignited after weighing, the loss in weight being determined on cooling. The difference between the two weighings gives the amount of the cellulose in 10 gm. of the soil mixture; the percentage is obtained by multiplying by 10. In cases where the greatest accuracy is desired, account may be taken of the amount of water remaining after the drying of the soil sample in the thermostat; this residual water must be estimated in a parallel test.

In our preliminary trials the cellulose was dried in the alundum crucible to constant weight, after which the incineration was carried out direct, i.e., without transferring the cellulose to a platinum crucible. This procedure always gave high results because of the retention of more or less water by the porous material under the glaze. On igniting the crucible this residual water, of course, was lost, thus causing the error in question.

As the cellulose is extracted from the soil in the way described above, the incineration of the washed and dried cellulose precipitate cannot be avoided. Of the extract obtained by treating the soil with Schweitzer's reagent, 50 cc. was used without previous filtration, and it therefore sometimes happened that minute particles of soil were present therein; this, however does not affect the result if the precipitate is incinerated. In addition, the cellulose absorbs iron compounds, but not aluminum compounds, at least for the soil with which we are concerned. There is no objection to filtering the soil extract through asbestos or glass wool, but as this was not necessary, as was shown by the control analyses, it was naturally omitted.

The advantage of the alundum crucible over the Gooch crucible in work of this kind is evident; even if the latter is prepared with the greatest care, there is always the risk that particles of asbestos may become detached on account of the unavoidable changes in pressure, so that channels are formed through which a portion of the cellulose escapes. In working with an alundum crucible this error of course is avoided. Further, the Gooch crucible as a rule must be repacked, while the alundum crucible is always ready for the next analysis. To begin with, ordinary unglazed alundum crucibles were tried, but they soon proved unsuitable as the copper chloride could not be completely washed out. It was only when they had been glazed as described above that the difficulty was overcome. It nearly always happens that some copper salt creeps up

into the porous wall under the glaze, but with our present modification of the method, this does not influence the results.

The above described method of working can be applied only to mineral soils; when dealing with humus soils, the sample for analysis must be submitted to a further preparation consisting, according to Charpentier's directions, of the admixture of 10 per cent of unslaked lime. In this way the humus substances are fixed; otherwise they will prevent the solution of the cellulose in Schweitzer's reagent. The lime is carefully incorporated in the sample by grinding in a mortar after which the mixture is transferred to a beaker and dried at about 40°C. After drying, the mixture is ground once more, transferred back to the beaker, moistened with water and dried. The procedure is then as already described, except that the sample after shaking with the Schweitzer's reagent must stand for 2 to 3 days before the sedimentation is complete.

Turning to the results of the first series of experiments, the figures in table 1 show the influence of the different ammonium salts with equivalent amounts of ammonia nitrogen to be practically the same. Absolute agreement could hardly be expected in fermentation experiments of this kind. In pots V, a and b, 24.1 mgm. of ammonia nitrogen were added by mistake instead of 20.4 mgm.; hence the discrepancies in the cellulose figures for these pots. It is particularly interesting to note that in the pots containing *ammonium nitrate*, the effect was approximately double that observed in the pots containing the same amounts of ammonia nitrogen in the form of other salts. On the other hand, in the pots with half the amount of ammonium nitrate, (10.2 mgm. ammonia nitrogen) the amount of cellulose decomposed was about the same as in the other pots which contained 20.4 mgm. of ammonia nitrogen. This difference is obviously due to the simple fact that in ammonium nitrate there are two nitrogen atoms, one in each radical, and that both of these are equally available to the cellulose-decomposing organisms. The significance of nitrate nitrogen in cellulose fermentation was pointed out in 1904 by van Iterson (7).

Two further series of experiments were carried out on the lines just described, in which we restricted the number of different ammonium salts but included in each case a mixture of cow and horse manure, the amount of ammonium salt added being calculated on the basis of the content of ammonia nitrogen in the manure. Both series in other respects were quite identical with one another.

In order that the manure used be quite homogeneous, about 1 kgm. of 3 to 4 months' old manure was chopped to pieces, mixed with a small spade and put through a mincing machine. After another chopping up and mixing, it was again passed through the machine and mixed once more. From the resulting product, the different portions were directly weighed off for the cellulose pots, and also for the estimation of nitrogen and water.

In such investigations as are described below, one must of course have some guarantee that the method of analysis used for the estimation of ammonia in the manure really gives as accurate results as possible. If all the nitrogen

present in the manure as ammonia is not obtained in the method employed, e.g., if some of it is bound to the manure by adsorption, or, on the other hand, if nitrogen originating from higher nitrogenous compounds is split off as ammonia during the course of the analysis, the values obtained for ammonia nitrogen in the manure will naturally be wrong. Again, as the amounts of ammonia nitrogen added in the form of various ammonium salts must be regulated according to the ammonia nitrogen found in the manure by analysis, it is obvious that the method of analysis employed here must be perfectly reliable if really equivalent conditions are to be attained through the different additions. We have therefore subjected the methods available for the estimation of ammonia nitrogen in manure to a special examination.

In these estimations, made simultaneously, the methods of Boussingault and of Baragiola and Schuppli were compared. According to the former, 50

TABLE 2

Comparison of methods of Boussingault and of Baragiola and Schuppli

AMMONIA NITROGEN ADDED PER 50 GM. OF MANURE	AMMONIA NITROGEN			
	Boussingault method		Baragiola and Schuppli method	
	Recovered	Difference	Recovered	Difference
mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*
0.00	90.09	—	75.04	—
0.00	85.82	—	75.11	—
25.06	114.87	−1.85	99.89	0.25
25.06	113.75	−0.73	103.46	−3.32

gm. of the manure was treated with MgO and about 500 cc. of water; 1 cc. of paraffin oil also was added to prevent frothing. The mixture was boiled at ordinary pressure, and the liberated ammonia absorbed by 0.1 *N* H_2SO_4. The distillate collected amounted to about 300 cc. In Baragiola and Schupplis' method, also carried out on 50 gm. of manure, MgO and about 100 cc. of distilled water were added, and the mixture was distilled to dryness at a pressure of 15 mm. of mercury, at 35°C., the distillate being received in 0.1 *N* H_2SO_4. After the addition of some fragments of pumice, the entire distillate was boiled for several minutes to eliminate carbon dioxide, and titrated on cooling with 0.1 *N* NaOH and methyl red. Both methods were controlled thus: To 50 gm. of the same manure was added 25 cc. of ammonium sulfate solution of known strength, and this mixture was then analyzed for ammonia. The mixture was first allowed to stand for 1 hour with occasional shaking in order to get the adsorption equilibrium established. This investigation is set forth in table 2. The percentage loss is calculated on the $(NH_4)_2SO_4$ nitrogen.

The parallel estimations, on the whole, show good agreement. For the manure alone, Baragiola and Schuppli's method gave about 15 per cent less

ammonia than Boussingault's. Both methods accounted quantitatively for the nitrogen added with the ammonium sulfate, which shows that no adsorption took place. It is thus impossible to decide on the basis of these figures which method is the right one to use, though the balance of probability is in favour of the vacuum method which offers milder conditions to the higher nitrogen compounds of the manure.

When the experiments were started it became necessary to make a choice, and we decided on the more convenient method of Boussingault. The *ammonia nitrogen figures for manure in tables 5 and 6, are based on Boussingault's method.* At the same time, the ammonia nitrogen in the manure was in both these cases also estimated by Baragiola and Schuppli's method, so that the results could be checked if necessary.

The scheme of the experiments was as follows:

Pots I, a and b: 1000 gm. soil plus 10 gm. filter paper, plus 30 cc. water,
Pots II a and b: 1000 gm. soil, plus 10 gm. filter paper, plus 10 gm. manure (16 mg. ammonia nitrogen) , plus 22.5 cc. water.
Pots III, a and b: 1000 gm. soil, plus 10 gm. filter paper, plus 20 gm. manure (32 mgm. ammonia nitrogen), plus 15 cc. water.
Pots IV, a and b: 1000 gm. soil, plus 10 gm. filter paper, plus 40 gm. manure (64 mgm. ammonia nitrogen).
Pots V, a and b: 1000 gm. soil, plus 10 gm. filter paper, plus 30 cc. $(NH_4)_2SO_4$ solution (= 32 mgm. ammonia nitrogen).
Pots VI, a and b: 1000 gm. soil, plus 10 gm. filter paper, plus 3.9 cc. NH_4NO_3 solution (= 16 mgm. ammonia nitrogen) plus 26 cc. water.
Pots VII, a and b: 1000 gm. soil, plus 10 gm. filter paper, plus 7.7 cc. NH_4NO_3 solution (= 32 mgm. ammonia nitrogen) plus 22.3 cc. water.
Pots VIII, a and b: 1000 gm. soil, plus 28 cc. water.

The water content of the manure and filter paper was estimated at about 80 per cent and 6 per cent, respectively, and the addition of water to the various pots was regulated accordingly. That is, the water content was the same in all the pots as in no. IV, a and b, or between 18 and 19 per cent, which for mineral soils of the type used in our experiments (clay soil) is the optimum for bacteriological metabolism experiments.

Two analyses of the filter papers used (Munktell no. 10) gave the following results:

	WATER	ASH	CELLULOSE (BY DIFFERENCE)
	per cent	*per cent*	*per cent*
A	5.73	0.42	93.85
B	5.87	0.64	93.49

From these figures, the amount of cellulose added was calculated at 0.90 per cent.

At the same time, a series of direct determinations of cellulose also were made on the filter paper by Charpentier's method. The amounts of finely cut filter

paper given in table 3 were placed in Lovén flasks, and the Schweitzer's reagent added directly. The calculated amounts given in the table are obtained by the multiplication of the weight (in grams) of the filter paper used, by 0.9349; for the difference between the weight of the sample of the same filter paper and the water plus ash, had previously given the figure 93.49 per cent of cellulose. The values found by direct estimation thus agree fairly well with those obtained by difference.

TABLE 3

Direct determinations of cellulose in filter paper

SAMPLE NUMBER	FILTER-PAPER TAKEN	CELLULOSE		DIFFERENCE	CELLULOSE FOUND
		Calculated	Found		
	gm.	*gm.*	*gm.*	*gm.*	*per cent*
1	0.2098	0.1961	0.1944	0.0017	92.66
2	0.2099	0.1962	0.1990	−0.0028	94.81
3	0.1029	0.0962	0.0968	−0.0006	94.07
4	0.1030	0.0963	0.1004	−0.0041	97.48
5	0.0301	0.0281	0.0284	−0.0003	94.35
6	0.0301	0.0281	0.0304	−0.0023	101.00

As part of the cellulose might be retained in the soil by adsorption, and thus escape estimation, some further investigations were made in this connection. Into each Lovén flask was placed 20 gm. of soil, previously dried at 42°C., which contained 2.26 per cent of water. The amounts of cellulose given in

TABLE 4

Adsorption of cellulose by soil

SAMPLE NUMBER	CELLULOSE ADDED		CELLULOSE FOUND		CELLULOSE LOSS ACCORDING TO B	
	Filter paper	Cellulose in filter paper	A	B		
	gm.	*gm.*	*gm.*	*gm.*	*per cent*	*mgm.*
1	0.2104	0.1967	0.1914	0.1923	2.24	4.4
2	0.2106	0.1969	0.1928	0.1937	1.63	3.2
3	0.0975	0.0912	0.0834	0.0838	8.11	7.4
4	0.0995	0.0930	0.0874	0.0878	5.59	5.2
5	0.0329	0.0308	0.0252	0.0253	17.86	5.5
6	0.0304	0.0284	0.0242	0.0243	14.44	4.1

table 4 also were added. The corresponding amounts of pure cellulose are calculated according to the foregoing analyses. The Schweitzer's reagent was added immediately, after which the estimations were made as usual. The cellulose figures given under A were obtained by multiplying the analytical figures by 2, while under B, the water in the soil was taken into consideration.

On an average, 5.0 mgm. of cellulose out of 20 gm. was adsorbed by the soil in question (table 4). In the cellulose estimations in the two last series, corrections were made both for the residual water in the soil after drying, and

for the cellulose adsorbed by the soil. The results of these two series, both carried out according to the same scheme, as given in tables 5 and 6, must therefore be regarded as representing the highest degree of accuracy obtainable by the technique which we employed. Pots VIII, a and b, are not included in tables, as these blank tests always gave negative results with respect to cellulose content. The parallel pots generally show as good mutual agreement in

TABLE 5

Cellulose decomposition in soil—corrections made for residual water in soil

POT NUMBER	ADDITIONS PER KILOGRAM OF SOIL		IMMEDIATELY		2 MONTHS		4 MONTHS	
			Cellulose	Average	Cellulose	Average	Cellulose	Average
		mgm. NH_4-N	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Ia	None		0.78	0.87	0.52	0.53	0.51	0.48
Ib			0.95		0.53		0.44	
IIa	10 gm. manure	16	0.82	0.80	0.49	0.51	0.33	0.31
IIb			0.78		0.52		0.29	
IIIa	20 gm. manure	32	0.78	0.85	0.40	0.38	0.23	0.24
IIIb			0.92		0.36		0.26	
IVa	40 gm. manure	64	0.78	0.80	0.26	0.27	0.20	0.18
IVb			0.83		0.28		0.15	
Va	$(NH_4)_2SO_4$	32	0.80	0.85	0.37	0.35	0.28	0.26
Vb			0.88		0.34		0.23	
VIa	NH_4NO_3	16	0.78	0.83	0.34	0.34	0.26	0.27
VIb			0.89		0.34		0.28	
VIIa	NH_4NO_3	32	0.79	0.81	0.23	0.22	0.11	0.13
VIIb			0.82		0.21		0.16	

cellulose content as could reasonably be expected. It is quite remarkable that the initial values found differ so greatly from those calculated (about 0.90 per cent of cellulose), the average error amounting to about 8 per cent. As the initial values almost without exception are too low, the error must lie in the technique. Since the method of analysis itself is characterized by great accuracy, as shown by tables 3 and 4, it is obvious that the sampling or the mixing of the soil and cellulose must be at fault. To settle this question, we made the experiments reported below.

Into 1 kgm. of the same soil as was used in all the experiments, was mixed 10 gm. of filter paper which had been passed twice through a meat-mincing machine. The cellulose thus obtained was much like meal and could easily be mixed with the soil so as to produce an apparently homogeneous mixture. From this, five samples of 20 gm. each were taken for the estimation of cellulose, while a sample of unmixed soil was taken for a blank test. As the soil

TABLE 6

Cellulose decomposition in soil—corrections made for cellulose adsorbed by the soil

POT NUMBER	ADDITIONS PER KILOGRAM OF SOIL		IMMEDIATELY		2 MONTHS		4 MONTHS	
			Cellulose	Average	Cellulose	Average	Cellulose	Average
		mgm. NH_4-N	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Ia	None		0.83	0.79	0.45	0.42	0.48	0.45
Ib			0.75		0.39		0.41	
IIa	10 gm. manure	17.5	0.75	0.80	0.41	0.41	0.33	0.33
IIb			0.85		0.42		0.33	
IIIa	20 gm. manure	35.0	0.82	0.88	0.34	0.36	0.25	0.25
IIIb			0.93		0.37		0.25	
IVa	40 gm. manure	70.0	0.79	0.83	0.21	0.24	0.17	0.18
IVb			0.87		0.27		0.18	
Va	$(NH_4)_2SO_4$	35	0.78	0.78	0.26	0.28	0.23	0.23
Vb			0.78		0.30		0.23	
VIa	NH_4NO_3	17.5	0.83	0.88	0.32	0.32	0.24	0.24
VIb			0.93		0.32		0.24	
VIIa	NH_4NO_3	35	0.70	0.75	0.15	0.15	0.12	0.11
VIIb			0.79		0.15		0.11	

was used just after drying at 42°C., and thus contained only 1.15 per cent of water, the Schweitzer's reagent was added direct, the cellulose being estimated as usual. The results are given in table 7, corrected for moisture in the soil as well as for adsorption.

The investigation shows that when using ground filter paper, the cellulose figures obtained are very near the theoretical values. The cut fragments of filter paper, about 2 by 2 mm. in size, as used before, cannot be mixed with

the particles of soil to the same degree as the cellulose meal. It follows that in weighingout the sample, some of the bits of filter paper became separated from the mixture and remained behind. Having cleared up this point, we changed over to ground filter paper in the cellulose fermentation experiments now in progress. Even if the initial values, and therefore the other cellulose figures given in tables 5 and 6, are subject to a relative error of about 8 per cent, this does not hinder the interpretation of the results.

It may be said that these results confirm in a very striking manner the theory that the ammonia nitrogen in the manure is the cause of the favorable influence of the latter on cellulose fermentation in soil. The amounts of cellulose found after a certain time in the pots containing equivalent amounts of ammonia nitrogen agree with one another, while on the other hand, the halved and doubled amounts of ammonia nitrogen give correspondingly higher and

TABLE 7

Cellulose determinations on ground filter paper mixed with soil

SAMPLE NUMBER	CELLULOSE	
	Calculated	Found
	per cent	*per cent*
1	0.925	0.927
2	0.925	0.880
3	0.925	0.846
4	0.925	0.945
5	0.925	0.865
Blank	0.000	0.000
Mean value		0.893±0.019

lower figures, respectively, for the undecomposed cellulose found in the soil. Still closer agreement is obtained if the values for the ammonia nitrogen added with the manure are calculated from the results obtained by Baragiola and Schuppli's method. In this way we found 15, 30 and 60 mgm. of ammonia nitrogen for the manure pots in table 5, and 16, 32 and 64 mgm. for those in table 6. As we already pointed out, it is probable that the above method gives more accurate results, for in Boussingault's method the possibility of some of the higher nitrogenous compounds of the manure breaking down into ammonia is by no means excluded. If, therefore, the additions of ammonium salts are calculated, as we have done, on the basis of the results obtained by Boussingault's method for determining the content of ammonia nitrogen in manure, then the quantities of salts added will probably be too large. This again in effect will make the cellulose fermentation in the manure pots appear to be somewhat less vigorous, by comparison, than should be the case.

The ability of ammonium nitrate, to act as a "double" source of nitrogen as referred to above, is clearly expressed by the experiments set forth in tables 5 and 6, indicating the amount of ammonium nitrate equivalent to the stable

manure and ammonium sulfate in respect to ammonia nitrogen. It is seen that the ammonium nitrate is twice as effective as the manure and the ammonium sulfate, while in amount corresponding to half the equivalent of ammonia nitrogen its effect is exactly the same as that of the two other additions in question.

The results of these experiments may have a wider general significance than appears from the special investigations reported. In the Bacteriological Department of the Central Agricultural Experiment Station, a long series of experiments (2, 3 and 4) have been in progress for a number of years to elucidate the progress of the nitrification of stable manure in soil. These have shown that it is chiefly the ammonia nitrogen of the soil which is nitrified, while as a rule, by no means all of the available ammonia nitrogen is utilized. Now it is shown by the above investigations that the ammonia nitrogen of manure also affects the decomposition of cellulose in tilled soil in such a way that the amount of decomposition after a certain lapse of time stands in direct proportion to the amount of ammonia nitrogen added with the manure. These later investigations therefore confirm the former ones, and permit us to formulate the general rule that the effect of the nitrogen of stable manure during the first year of growth on the microbial metabolism in tilled soil may most probably be ascribed to the ammonia nitrogen of the manure. The remaining nitrogen in the manure consists for the most part of proteins from the epithelial cells of the intestinal tract and from microörganisms, that are being mineralized only very slowly.

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SUPPLEMENT

After the foregoing was written we have made some further experiments in order to determine definitely whether the microörganisms added with the stable manure are of any decided importance for the fermentation of cellulose in the soil. The experiments described above have shown that most probably only the ammonia nitrogen added with the manure is the cause for the favorable influence.

1. The same clay soil used in our earlier experiments was thoroughly mixed with finely ground filter paper (1 per cent) and then divided into two parts. The one portion was supplied with 2.3 per cent of stable manure, previously sterilized in an autoclave at 120°C. for 2 hours. The second part was supplied with 2 per cent of unsterilized manure. The ammonia content of the unsterilized manure was 0.163 per cent and of the sterilized manure 0.142 per cent. Both soil mixtures were put into 200 cc. bottles and stopped with paraffined corks provided with a short glass tube packed with cotton. Two bottles of each kind were prepared and then stored at room temperature. After two months the cellulose was determined in the usual manner and the following average values were obtained:

	per cent of cellulose
Unsterilized soil plus sterilized manure	0.63
Unsterilized soil plus unsterilized manure	0.57

2. The same soil was sterilized in an autoclave at 120°C. for 2 hours and then supplied with 1 per cent of ground filter paper. Then the mixture was transferred to 200 cc. bottles and sterilized in the autoclave at 105°C. for 15 minutes. This short sterilization at a rather low temperature was thought to be sufficient, the spores in the soil already having been killed by the first sterilization. On the other hand, the paper could not be mixed into the soil before the first sterilization as the cellulose tends to be decomposed at higher temperatures. The bottles were stopped with rubber stoppers provided with glass tubes packed with cotton. The stoppers were previously sterilized in alcohol and the glass tubes in a dry oven. Two of these bottles were inoculated with 2.3 per cent of sterilized manure and 1 per cent of unsterilized soil, two with 2 per cent of unsterilized manure and 1 per cent of unsterilized soil and two, finally, with 2 per cent of unsterilized manure only. These bottles were stored at room temperature together with the bottles mentioned above, and analyzed after two months for cellulose. The following averages were found:

	per cent of cellulose
Sterilized soil plus 2.3 per cent sterilized manure plus 1 per cent sterilized soil	0.13
Sterilized soil plus 2 per cent unsterilized manure plus 1 per cent unsterilized soil	0.14
Sterilized soil plus 2 per cent unsterilized manure	0.16

It appears unmistakable from both these experiments that the cellulose fermenters added with the manure do not cause the favorable influence of the manure upon the cellulose fermentation in the soil. This effect appears to

be due to the ammonia nitrogen added with the manure. As seen from the figures above, sterilized manure has just the same effect as unsterilized manure when, as in this case, the amounts of ammonia nitrogen are equivalent.

That the cellulose fermentation takes place so much more rapidly in case of sterilized soil merely may be attributed to the increase of the amount of ammonia nitrogen which enters during the sterilization by the splitting off of ammonia from higher nitrogen compounds. By analysis there were found 56.0 mgm. of ammonia nitrogen per kilogram of the sterilized soil, while the unsterilized soil was practically free from ammonia.

Experiments which are now being made in this laboratory by J. Arlington Anderson, indicate that this amount of ammonia nitrogen, 56.0 mgm. per kilogram of soil, which was split off by sterilization, is quite sufficient to establish the rapid cellulose fermentation found above.

SUMMARY

1. The method for determination of cellulose in soil, originally worked out by Charpentier in our laboratory, has been further modified and perfected by us. In its present form this method affords a valuable contribution to the technique of metabolism experiments in soil biology. It is possible to determine the power of the organisms present in various soils to decompose cellulose, and the influence of various factors on this process; just as the nitrifying power, nitrogen assimilation, carbonic acid formation, etc., are determined.

2. The favourable influence of stable manure upon cellulose fermentation in the soil, which was found by Charpentier is due to the nitrogen present in the manure which is available to microörganisms. Microörganisms added with the manure are of no practical importance in normal soils since sterilized manure acts in the same manner as unsterilized manure. The ammonia nitrogen in the manure can be exchanged by other ammonia compounds with the same result.

3. The cellulose fermentation in autoclaved soil, inoculated either with manure or unsterilized soil, proceeds much more rapidly than in unsterilized soil because of the ammonia nitrogen split off from higher nitrogen compounds during sterilization.

RESIDUAL EFFECTS OF FORTY YEARS CONTINUOUS MANURIAL TREATMENTS. I. EFFECT OF LIME ON DECOMPOSITION OF SOIL ORGANIC MATTER

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The origin of the idea of greater destruction of soil organic matter by caustic lime than by lime carbonates may be traced to early studies made by Hess (5) on certain plots of the "General Fertilizer Series" located at this station. The interpretation by Hopkins (6) of these data gave prominence to this work and led to a wide acceptance of his teachings on this important subject resulting in an unjust discrimination against the use of lime other than neutral carbonates. Frear (3, p. 151) under whose direction the studies of Hess were conducted made the following statements concerning the far reaching results of Hopkins' conclusions:

> This experiment and the conditions have been thus fully presented and discussed, because the references of 1899–1900 were made the basis for conclusions much farther reaching than any the writer ventured to make; and these, in turn, have constituted the grounds for an extensive commercial exploiting of the merits of ground limestone as contrasted with the old-fashioned burnt lime applications, which are declared to burn up the humus, whereas the carbonate is said to conserve it.

Since the studies of Hess in 1899–1900, the same plots have been thrice sampled and studied in a similar manner, in 1911 by MacIntire (9) and 1915 and 1921 by the authors of this paper. Each succeeding study where the soil of the *four tiers* was composited into one sample, representative of each treatment, gave results quite similar to the earlier studies. The soil treated with limestone in every instance contained more organic matter and nitrogen than that treated with burned lime. However, when the plots of each tier were separately studied, as was done in case of the 1921 samples, the data secured threw a new light on this much mooted question and leads to conclusions entirely contrary to those cited above. The primary purpose of this paper is, therefore, to present this new evidence supported by more detailed studies concerning the comparative effects of these two forms of lime on the decay of soil organic matter at the end of forty years of continuous treatment during which time the soils have received total applications equivalent to 80,000 pounds per acre of lime carbonate and 40,000 pounds of burned lime respectively. The data secured as the result of the earlier studies where the four tiers are composited as a unit will be presented together with the 1921 figures

computed to the same basis. These figures will afford an opportunity of studying to a limited extent the progressive changes in organic carbon and total nitrogen content of these soils as the result of the two lime treatments in comparison with the untreated soil.

PENNSYLVANIA FIELD PLOT EXPERIMENTS

The detailed plan and scope of these old field experiments have been published in several reports dealing with the yields of the various treatments (4) and will be described here only in relation to the particular plots under consideration. In the scheme of treatments are included studies of the comparative values of burned lime[1] and pulverized limestone, applied without further manurial treatment, on plots numbered 23 and 34, respectively. A 4-year rotation had been followed consisting of corn, oats, wheat and hay (mixed clover and timothy). Two tons of burned lime have been applied to each corn crop and 2 tons of limestone to both the corn and wheat ground. From

TABLE 1

Summary of the results secured on the 1899, 1911, 1915, and 1921 (samples of the four tiers composited)

PLOT NUMBER	SOIL TREATMENT	ORGANIC CARBON				NITROGEN			
		1899	1911*	1915	1921	1899	1911	1915	1921
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1, 14, 24, 36	Untreated	1.64	1.4821	1.5385	1.4277	0.1244	0.1122	0.1150	0.1110
23	Burned lime	1.47	1.4661	1.5227	1.4509	0.1172	0.1199	0.1145	0.1155
34	Limestone	1.67	1.6929	1.7971	1.7355	0.1341	0.1222	0.1205	0.1252

* The 1911 studies include only one check plot (no. 24).

1881 to 1921, therefore, the corn ground has received a total of 20 tons of burned lime as compared to 40 tons of limestone for corn and wheat. Reference to the diagram will show that four tiers are included in the experiment; thus each of the four crops are grown every year. Five untreated plots are shown on the diagram, only four of which are included in the chemical studies.[2]

A review of the above figures shows that in each case the limestone treated soil contains more organic carbon and nitrogen. The later studies apparently serve to substantiate the work of Hess.

Conclusions by Hess, 1899

From the above, the destructive effects of lime in the caustic condition, upon the humus is clearly shown. The amount of nitrogen is decreased by a continued use of caustic lime without the additions of other manures.

[1] From 1881 to 1910 the burned lime was slaked in piles before spreading. Since 1910 raw ground lime (CaO) has been used.

[2] Plot 8 has always given abnormal yields and for this reason is excluded from the composite samples of untreated plots.

Conclusions by Frear 1899

The action of caustic lime to decrease the humus of the soil (C × 1.724) is very distinctly shown in these results from field trials. The annual loss, compared with that of the unfertilized plot is 0.21 ton in excess, equivalent to the quantity in one ton of stable manure. The deficiency of nitrogen on the limed plots corresponds with the results of laboratory trials, but the relative gain of nitrogen on the land treated with ground limestone is unexpected and merits further and more detailed study. In the absence of data as to the composition of the soil at the time when the fertilizer experiment began, it is impossible to discover whether there has been an absolute loss or gain of humus in any case (2).

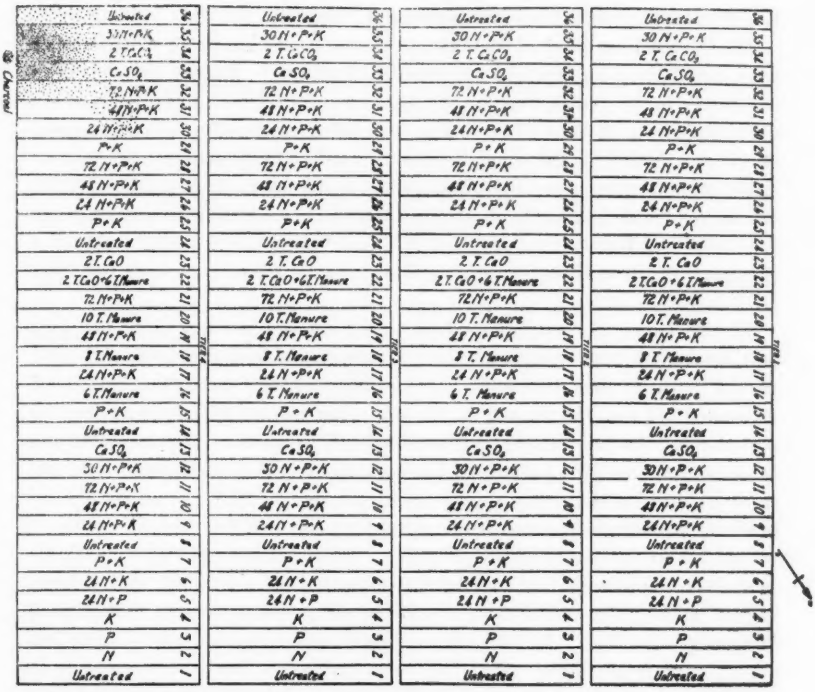

FIG. 1. PLAN OF PENNSYLVANIA FIELD PLOT EXPERIMENTS "GENERAL FERTILIZER SERIES" 1881–1921

Nitrogen applied as dried blood on plots 2, 12, 35, 9, 10, 11, 17, 19 and 21.

Nitrogen applied as nitrate of soda on plots 26, 27, 28 and as sulfate of ammonia on plots 30, 31 and 32.

Conclusions by Hopkins based on the figures of Hess

The data, as stated by Hopkins, indicate that the effect of caustic lime as compared with ground limestone was equivalent to the destruction of 37½ tons of farm manure in 16 years, or more than two tons per year to the acre (6); also that there is a liberation of more than $7.00 worth of nitrogen for every

ton of burned lime used during the 16 years. In a like manner the difference of 0.2 per cent of organic carbon between the two limed plots was computed to the equivalent of 37.6 tons of fresh manure.

It is of interest to note that in computing the difference of 0.0169 per cent nitrogen to the equivalent of pounds per acre Hopkins used as his weight per acre 9 inches of soil 2,224,800 pounds as suggested by Hess. However, the carbon figures were computed on the basis of 2,700,000 pounds per acre 9 inches. Hopkins thus gets an actual difference of organic matter greater than reported by Hess. (Hess computes a difference of 3.9 tons of humus (C × 1.724) in favor of limestone and Hopkins 4.7 tons).

The far-reaching effect of these computations is well known to those familiar with the "Illinois System of Permanent Agriculture." Burned lime has been eliminated in the middle west largely as the result of these figures, while in the east Hopkins' conclusions concerning lime have apparently not had so great an effect. Although the work of Hess is based on experiments conducted at this station no reference to his findings has ever been made in publications at the Pennsylvania Station in an attempt to show the superiority of one form of lime over another. As the result of this more conservative stand, eighty-five producers of the various forms of agricultural lime are offering their products for sale in this state.

The 1899 and 1911 results have been fully discussed by Frear (3, p. 141–148) and need no further comment here. A comparison of the 1899 and 1915 results indicates that during the sixteen years between these two periods the untreated soil lost 188 pounds of nitrogen; that treated with burned lime, 54 pounds; and the soil treated with limestone, 272 pounds. The untreated soil in 1899 contained 144 pounds of nitrogen in excess of the burned lime soil while in 1915 the difference is only 10 pounds and in 1921 the untreated soil contains 90 pounds less than the burned lime soil. If the organic carbon is computed to the equivalent of pounds of organic matter per acre 2,000,000 pounds it will be seen that in 1899 the untreated soil contained 5861 pounds organic matter in excess of the burned lime soil as compared to a difference of 906 pounds in 1915. In 1921 the untreated soil contained 800 pounds less than found on the limed soil. The untreated soil is therefore decreasing in both nitrogen and organic matter at a greater rate than the lime treated soil. The following summary shows the increase (+) or decrease (−) of nitrogen and organic matter on the limed soils above that found on the untreated soil, expressed in pounds per acre at the end of 18, 36, and 40 year periods.

TREATMENT	ITEM	AFTER 18 YEARS	AFTER 36 YEARS	AFTER 40 YEARS
		pounds	*pounds*	*pounds*
Burned lime	Gain or loss of nitrogen	−144	−10	+90
Burned lime	Gain or loss of organic matter	−5,861	−546	+800
Limestone	Gain of nitrogen	+194	+110	+284
Limestone	Gain of organic matter	+1,035	+8,915	+10,713

Note: The 1911 figures are omitted due to the fact that only one untreated plot was included.

The apparent superiority of the limestone treatment is brought out in this summary. There is a marked increase in organic matter and nitrogen greatly in excess of that shown by the burned lime soil. This unusual condition which gave rise to the teachings concerning the superiority of limestone is due, as will be shown later to the presence of a *charcoal deposit* on the limestone plot of tier 4, the significance of which will be discussed in the succeeding pages.

Table 2 shows the average annual yields for the first forty years of the experiment. It will be noted that up to the sixth rotation with the exception of the first, the untreated soil has outyielded the burned lime plot, after that period the untreated soils fall behind. The soil treated with limestone, however,

TABLE 2

Yield of the four crops based on the average pounds of dry matter produced in each of the ten rotations 1881–1921

TREATMENT	AVERAGE ANNUAL YIELDS OF DRY MATTER PER ROTATION ON 4 ACRES										
	1882–1885	1886–1889	1890–1893	1894–1897	1898–1901	1902–1905	1906–1909	1910–1913	1914–1917	1918–1921	1882–1921
	pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
Untreated (Plots 1,8, 14, 24, 36)	14,153	14,784	14,474	11,567	8,685	10,119	8,969	9,073	8,559	7,909	10,829
Burned lime.....	14,467	13,438	12,930	10,597	7,733	11,389	9,392	12,236	11,293	10,867	11,434
Limestone..	15,701	14,807	14,751	12,909	9,748	11,817	10,301	11,589	11,372	10,905	12,390

TABLE 3

Relative yields based on the first rotation of the untreated soil taken as 100

	ROTATIONS										AVERAGE
	1	2	3	4	5	6	7	8	9	10	
Untreated soil.....	100	104	102	81	61	71	63	64	60	56	77
Burned lime.....	102	95	91	75	55	80	66	87	79	77	81
Limestone.....	119	105	104	91	69	83	73	82	80	77	88

has outyielded the untreated plots throughout the ten rotations. A comparison of the yields of the two limed plots shows that the limestone treated soil has given a greater total yield of dry matter in every rotation with one exception. The apparent superiority of the limestone treated soil is due for the most part to the variation in the original fertility of the soil. If, therefore, the yields of the nearest check plot to each of the limed plots are considered rather than the average of all the checks, the actual difference in yields due to the two forms of lime becomes insignificant Table 2 shows that the limestone plot has produced an average yield of dry matter of 956 pounds in excess of burned lime, however, if the differences in original fertility of these plots are considered as measured by the difference in yields of the nearest checks (36

and 24) the difference becomes only 268 pounds. A study of the probable error due to the variability of these plots as measured by Gardner, Noll, and Lewis (4) shows that the odds in favor of limestone are only 6 to 1. To be significant the odds should be at least 30 to 1.

A study of table 3 shows that at the end of the fifth rotation the burned lime treatment begins to outyield the untreated plots.

DETAILED STUDY OF THE LIMED AND UNLIMED SOILS OF EACH TIER OF PLOTS BASED ON THE 1921 SAMPLES (1881–1921)

The data secured from earlier studies of these old plots present evidence contrary to the results secured from various laboratory, field and greenhouse studies along similar lines as reviewed by Frear (3). The data secured from previous studies of the lime and limestone plots were the result of composite soils. Such investigations eliminated the possibility of securing information concerning any abnormal soil variation on an individual tier that might be responsible for the balance of nitrogen and organic carbon found in each preceding study to be present on the limestone treated soil in such amounts as not to be accounted for by the differences in yield. In the hope of throwing new light on the cause of the differences in organic carbon and nitrogen content between these limed soils and at the same time to add to our present knowledge concerning the reason for pronounced variations in the growth of the several crops on an individual plot, a detailed study of each plot of the series was undertaken in 1921 with reference to soil variability.

PLAN OF THE INVESTIGATION

Each plot was divided equally into nine areas by stretching strings across each tier of plots at intervals of 29.2 feet. Six borings were made in each of the nine areas and composited into one sample. Nine samples were therefore secured from each of the 144 plots totaling 1296, which will be referred to as sub-samples. Each sub-sample was then spread out on a sheet of paper arranged in the order secured in the field. This gave an excellent opportunity to study the variations in the color of the soil of each plot at 29.2 feet intervals.

Aside from the normal variation that would be expected on this residual soil of variable topography there appeared no abnormal condition on the plots of tiers 1, 2 and 3. When the sub-samples of tier 4 were arranged in order, however, it was at once seen that several plots on the south end of the tier showed abnormal changes in the color of the respective areas varying from the normal light brown of the Hagerstown series to black at the extreme south end. This condition was found on plots 32, 33, 34 (limestone), 35, and to a lesser degree plots 30, 31, and 36. The other plots including the burned lime soil showed a normal variation.

Black color due to charcoal

Examination of these black areas with special reference to the limestone soil disclosed the presence of particles of charcoal which varied from particles the size of a field pea to a finely divided powder thoroughly incorporated with the soil mass. The grass division strips which separate the plots were examined and found to show the same condition. The charcoal therefore has been present in the soil since some time prior to 1868 at which time the plots were laid out.

Probable source of the charcoal

Located within one mile of the plots still stands the remains of one of America's oldest charcoal iron furnaces, one of several located in Center County. This furnace was put into operation in 1792 and continued until 1809 and again from 1825 to 1858. Throughout this section of Center County were located charcoal pits operated to supply material for this and several other iron furnaces in this section of Pennsylvania. The charcoal found on the plots no doubt is the residue from one of these old pits.

VARIATIONS IN ORGANIC MATTER AND NITROGEN ON THE LIMESTONE PLOT OF TIER 4 AS COMPARED TO THE BURNED LIME SOIL

Examination of the soil at each end of the two plots shows the influence of the incorporated charcoal on the organic carbon and nitrogen content of the limestone soil and the amount in excess of that found on the burned lime treated soil of this tier is sufficient to account for the difference between these two plots as shown in earlier studies.

The burned lime soil shows a variation of 264 pounds nitrogen per acre and 8613 pounds of organic matter per acre between the two ends of the plot as compared to 1006 and 128,229 pounds respectively in case of the limestone plot. The N–C ratio on the limestone plot varies from 1/11.83 to 1/29.11 as compared to 1/12.37 for the normal ratio shown in tables 5, 6 and 7.

The balance of nitrogen and carbon found on the limestone soil as shown by earlier studies including the four tiers may be accounted for by consideration of the difference shown in table 5 including also the small differences shown in tables 6, 7, and 8.

Reference to table 1 will show that the limestone soil apparently is increasing in organic matter as compared to the burned lime treatment. The actual differences in favor of limestone between the four periods of sampling are as follows: 6896, 7820, 9461, and 9913 pounds of organic matter, respectively. These differences are, however, due not to the actual accumulation of organic matter on the limestone treated soil as would naturally be inferred from the above figures, but to the difference in the methods of securing samples. The number of borings taken per plot at each sampling period was 5, 10, and 54 respectively. The charcoal deposit covers approximately forty per cent of the

limestone plot on tier 4. The amount of charcoal incorporated with the soil is greatest on area nine and gradually decreases until area six is reached where the soil appears normal. There is, however, no sharp line of demarcation. The increased number of borings taken at each succeeding period of study would include relatively more of the soil of area 9.

The question naturally arises in the mind of the reader as to why this charcoal was not earlier discovered. As stated before, the previous studies included a composite sample of the four tiers. The proportion of charcoal soil thus became relatively small. The small charcoal particles may be mistaken for partly decayed plant residues at the time the soil is prepared for analysis. The larger particles shown in the accompanying plate were originally coated

TABLE 4

Influence of the charcoal deposit on the organic carbon and nitrogen content of the limestone plot on tier 4

	TREATMENT	TOTAL NITROGEN PER ACRE		ORGANIC CARBON	ORGANIC MATTER PER ACRE	NITROGEN-CARBON RATIO
		per cent	*pounds*	*per cent*	*pounds*	
North End, 117 feet	Burned lime	0.1118	2,236	1.2855	44,324	1 to 11.49
	Limestone	0.1305	2,610	1.5448	53,263	1 to 11.83
South End, 58 feet (areas 8 and 9)	Burned lime	0.1250	2,500	1.5353	52,937	1 to 12.26
	Limestone	0.1808	3,616	5.2637	181,492	1 to 29.11

TABLE 5

TREATMENT	TOTAL NITROGEN PER ACRE		ORGANIC CARBON	ORANIC MATTER PER ACRE C × 1.724 × 2,000,000	N-C RATIO	AVERAGE N-C RATIO OF TIERS 1, 2, 3
	per cent	*pounds*	*per cent*	*pounds*		
Burned lime	0.1133	2,266	1.360	46,983	1 to 12.00	1 to 12.75
Limestone	0.1491	2,982	2.593	89,047	1 to 17.39	1 to 12.36

with fine silt and adhering clay and do not expose the fresh black surface in the manner shown. These particles may have easily been mistaken for gravel or small irregular stones found in abundance on the plots. Reference to the diagram of the plots will show the presence of the charcoal area indicated by small dots, the number of which are in proportion to the amount of charcoal present. A detailed soil survey was made to determine the proportion of the areas affected.

THE RELATIVE AMOUNTS OF ORGANIC MATTER AND NITROGEN FOUND ON PLOTS OF TIERS 1, 2, AND 3

After the soils had become air dried in the manner indicated, that representing each area was prepared for analysis by sifting through a 1-mm. screen in

the usual way. Aliquots of the nine areas were composited into one sample representing the respective plot. The remainder of the soil of each area was reserved for future study. The sifted soil was ground to pass a 100-mesh screen.

ANALYTICAL METHODS

Total carbon was determined by the usual dry combustion method using a multiple unit electric furnace, mineral carbon by the dilute phosphoric acid method, nitrogen by the use of the Gunning method modified to include nitrate nitrogen. The Grandeau method, as described by Wiley (10), the estimation of alkali soluble humus.

TABLE 6

Organic carbon and nitrogen found on plots of tier 1

	PLOTS 1, 14, 24, 36 (UNTREATED)	PLOT 23 (BURNED LIME)	PLOT 24 (LIMESTONE)
Organic carbon, *per cent*	1.6534	1.7772	1.6888
	1.6411	1.7513	1.7104
	1.7409	1.7835	1.6874
	1.7191	1.7780	1.6709
Average	1.6886	1.7725	1.6894
Equivalent pounds per acre organic matter*	58,223	61,116	58,251
Nitrogen, *per cent*	0.1215	0.1294	0.1302
	0.1205	0.1288	0.1322
	0.1252	0.1312	0.1300
	0.1232	0.1312	0.1294
Average	0.1226	0.1302	0.1305
Equivalent pounds per acre	2452	2604	2610
Nitrogen—carbon ratio	1:12.61	1:13.74	1:12.97
	1:13.62	1:13.52	1:12.94
	1:13.89	1:13.59	1:12.95
	1:13.95	1:13.55	1:12.91
Average	1:13.77	1:13.61	1:12.97

* Organic C × 1.724 × 2,000,000.

Tables 6, 7, and 8 show the results secured when each tier was separately studied.

The data presented in tables 6, 7, and 8 and summarized in table 9 secured as the result of the 1921 investigations, show that the relationship between the burned lime and limestone soils is entirely contrary to the earlier studies. By elimination of the plots of tier 4 an opportunity is given for the first time to study the actual comparative effects of these two forms of lime. In drawing our conclusions we may consider each tier as a separate field on which have been applied 40,000 and 80,000 pounds per acre respectively of burned lime and pulverized limestone. Ten complete rotations have been completed in each case. At first only duplicate determinations were made by the junior

TABLE 7

Organic carbon and nitrogen found on plots of tier 2

	PLOTS 1, 14, 24, 36 (UNTREATED)	PLOT 23 (BURNED LIME)	PLOT 34 (LIMESTONE)
Organic carbon, *per cent*	1.3630	1.4406	1.4148
	1.3951	1.4210	1.4287
	1.4360	1.4475	1.4423
	1.3616	1.4169	1.4175
Average	1.3889	1.4315	1.4258
Equivalent pounds per acre organic matter	47,822	49,358	49,162
Nitrogen, *per cent*	0.1052	0.1162	0.1116
	0.1070	0.1133	0.1142
	0.1082	0.1192	0.1144
	0.1050	0.1122	0.1122
Average	0.1064	0.1152	0.1131
Equivalent pounds per acre	2128	2304	2262
Nitrogen—carbon ratio	1:12.95	1:12.39	1:12.68
	1:13.04	1:12.53	1:12.51
	1:13.27	1:12.15	1:12.61
	1:12.96	1:12.62	1:12.63
Average	1:13.05	1:12.43	1:12.61

TABLE 8

Organic carbon and nitrogen found on plots of tier 3

	PLOTS 1, 14, 24, 36 (UNTREATED)	PLOT 23 (BURNED LIME)	PLOT 34 (LIMESTONE)
Organic carbon, *per cent*	1.2449	1.2607	1.2438
	1.1729	1.2443	1.2247
	1.2340	1.2182	1.2451
	1.1579	1.2345	1.2206
Average	1.2024	1.2394	1.2336
Equivalent pounds per acre organic matter	41,459	42,735	42,535
Nitrogen, *per cent*	0.1002	0.1042	0.1088
	0.0990	0.1038	0.1072
	0.1000	0.1022	0.1094
	0.0982	0.1032	0.1072
Average	0.0994	0.1034	0.1083
Equivalent pounds per acre	1988	2068	2164
Nitrogen—carbon ratio	1:12.42	1:12.09	1:11.43
	1:11.85	1:11.99	1:11.42
	1:12.34	1:11.91	1:11.38
	1:11.79	1:11.96	1:11.38
Average	1:12.10	1:11.98	1:11.40

author. However, a study of the data brought out the fact that the actual differences in organic carbon and nitrogen content between the two plots were in some cases actually less than the difference between two closely checked determinations. It was thought advisable, therefore, to run a second duplicate set of determinations on the same samples and thus reduce the experimental error and at the same time afford an opportunity of making probable error studies. In each table, therefore, the average results are based on four separate determinations on the same sample.

A study of the results secured on the three series of plots shows that in each case the burned lime soil contains slightly more organic matter while the limestone plot shows a slight balance of nitrogen on tiers 1 and 3. The actual differences, however, are within the experimental error and the odds in each case as shown later are insignificant.

TABLE 9

Summary of tables 7, 8, and 9 showing the average results secured on the plots of tiers 1, 2, and 3

	PLOTS 1, 14, 24, 36 (UNTREATED)	PLOT 23 (BURNED LIME)	PLOT 34 (LIMESTONE)
Organic carbon, *per cent*	1.4266	1.4811	1.4496
Equivalent organic matter, *pounds per acre*	49,168	51,070	49,983
Nitrogen, *per cent*	0.1094	0.1162	0.1172
Nitrogen, *pounds per acre*	2188	2324	2344
Nitrogen-carbon ratio	1 to 13.04	1 to 12.75	1 to 12.37

THE SIGNIFICANCE OF THE DIFFERENCES IN ORGANIC CARBON AND NITROGEN AS AFFECTED BY LIMING[3]

As already stated, in connection with the studies of Hess, the comparatively small differences in organic carbon and nitrogen found in favor of the limestone treated soil were made the basis for rather exaggerated claims concerning the merits of limestone as compared with burned lime. In order, therefore, to safeguard the 1921 data it seems advisable to determine mathematically if the differences in organic carbon and nitrogen are really significant or rather if the odds are in favor of any one treatment.

If the means of the chemical determinations are taken, the odds may by "Students" method be computed in favor of the plots having the highest content of organic carbon or nitrogen. This method of interpreting experinental data and its application are fully discussed by Love and Brunsen (8) and by Love (7). From the mathematical study of the data presented in tables 6, 7, and 8, the following conclusions were drawn:

The odds indicate that the gound limestone and the burned lime plot are not significantly different in their content of organic carbon nor in content of nitrogen. When the limed plots

[3] The computations from which the conclusions are drawn were made by Dr. C. F. Noll of the Department of Agronomy.

are compared with the untreated check plots in content of organic carbon the burnt lime plot only seems significantly higher than the check plots. In nitrogen content both lime plots are significantly higher than the checks.

ALKALI SOLUBLE ORGANIC MATTER

It has been shown conclusively that lime has a tendency to reduce the amount of alkali soluble organic matter in the soil as compared to the same soil unlimed. The degree of depression of the "matiere noire" should be greater, therefore, on soils where the more active forms of lime are applied. In order, therefore, to study the behavior of the two forms of lime under consideration which have been applied in excessive amounts, the organic matter soluble in 4 per cent NH_4OH was determined after first leaching the soils with 1 per cent HCl. The organic carbon was also determined on the alkali extract by evaporation in a copper boat and subsequent determination of carbon in electric furnace. Although a slight loss of carbon occurs as has been shown by

TABLE 10

Alkali soluble organic matter and proportion of total organic carbon and nitrogen present in the extract, based on an average of tiers 1 and 3

	PLOTS 1, 14, 24, 36 (UNTREATED)	PLOT 23 (BURNED LIME)	PLOT 34 (LIMESTONE)
	per cent	*per cent*	*per cent*
Alkali soluble humus	1.043	1.005	0.925
Alkali soluble nitrogen	0.0610	0.055	0.0580
Alkali soluble carbon	0.3838	0.3764	0.3600
Total nitrogen soluble in NaOH	55.353	47.373	48.576
Total organic carbon soluble in NH_4OH	27.278	24.994	24.726

Ames and Gaither (1) and by studies now in progress by the authors, the error should be distributed throughout the determinations. The nitrogen soluble in 3 per cent NaOH was also determined in the usual way.

The unlimed soil shows a higher percentage of alkali soluble organic matter, than either of the limed plots. The proportion of the total nitrogen and organic carbon soluble in alkali is also higher in this soil. A comparison of the two differently limed soils shows a higher proportion of carbon associated with the "humus" on the burned lime soil and a lesser proportion of nitrogen.

SUMMARY

The following summation of facts is based on a study of the three differently treated plot soils at the end of forty years (1881–1921) of continuous cropping during which time 40,000 pounds of burned lime have been applied in one series in comparison with 80,000 pounds of pulverized limestone. Both limed soils are studied in relation to the untreated soil. The figures given are expressed on the acre basis (2,000,000 pounds).

1. The limestone soil contains as an average of the three tiers 20 pounds of nitrogen in excess of that found on the burned lime soil.

2. The burned lime treated soil contains organic matter in excess of the limestone treated soil as follows: tier 1, 2865 pounds, tier 2, 196 pounds; and tier 3, 200 pounds; average, 1087 pounds.

3. The limed soils contain as an average 1359 pounds of organic matter and 146 pounds of nitrogen in excess of that found on the untreated soil.

4. The N - C ratio of the three soils was found to be as follows: Untreated, 1/13.04, burned lime, 1/12.75, and limestone soil, 1/12.37.

5. Both limed soils show less alkali soluble humus than the untreated soil.

6. On the untreated soil 55.353 per cent of the total nitrogen is associated with the alkali soluble humus as compared with 47.975 per cent on the limed soils.

7. On the untreated soil 27.278 per cent of the total organic carbon is soluble in dilute ammonia as compared with 24.86 per cent on the limed soils.

8. The limestone treated soil has produced a total of 9560 pounds of air dry matter above that produced by the burned lime soil. In spite of this fact the burned lime soil contains 1087 pounds of organic matter in excess of the limestone soil.

9. During the second half of the experiment (1901–1921) the burned lime soil shows a reduction in yield of 6.7 per cent as compared to 17.5 per cent for the limestone soil and 12.9 per cent on the untreated soil.

10. As an average for 40 years the limestone soil has given 8.3 per cent greater yields than the burned lime treatment. At the same time the untreated plot (no. 36) nearest the limestone plot has produced yields 6.4 per cent in excess of the untreated plot (no. 24) adjoining the burned lime soil. The apparent increased yields of the limestone treatment above the burned lime soil is due, therefore, largely to the original difference in residual fertility.

Concerning the earlier studies made on these plots (1899, 1911 and 1915)

11. The origin of the idea concerning the destructive action of burned lime on soil organic matter is traced to the studies of Hess made in 1899.

12. The balance of nitrogen and organic carbon found on the limestone treated soil as the result of the earlier studies has been shown to have been derived from charcoal found on the limestone plot of tier 4.

13. The difference of 0.2 per cent of organic carbon and 0.0169 per cent nitrogen as found in the limestone soil as reported by Hess was computed by Hopkins to the equivalent of 75,200 and 75,000 pounds respectively of farm manure destroyed by the caustic action of burned lime.

14. The charcoal found on the limestone plot of tier 4 after having been incorporated in the soil for perhaps 75 years shows the following composition: organic carbon, 64.136 per cent; nitrogen, 0.25 per cent; loss on ignition (organic matter), 83.94 per cent; and ash, 16.06 per cent.

15. The charcoal was found to be present in sufficient quantity to furnish 47.55 per cent of the total organic carbon found on the plot. On the south end of the plot 70.8 per cent of the organic carbon was found to be derived from charcoal.

16. The condition and amount of the calcium applied as burned lime and limestone present in the soil after 40 years and the relative effect upon the ultimate reaction of the soil will be presented as the second of a series of papers dealing with a study of these old plots.

CONCLUSIONS

1. The determination of the experimental error of the 1921 data shows conclusively that there is no significant difference in the action of burned lime and limestone on soil organic matter at the end of 40 years of continuous treatment during which time the two forms of lime have been applied in amounts eight times that now recommended for soils of limestone origin.

2. Both the limestone and burned lime treated soils show a significant increase of nitrogen above that found on the untreated soil.

3. It has thus been shown that there is no evidence whatsoever to warrant the belief that burned or caustic lime has a destructive action on soil organic matter in excess of such action by lime carbonate. On the contrary, both forms of lime under the condition of this, the oldest lime experiment in existence, have conserved nitrogen and organic matter as compared to the untreated soil.

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PLATE

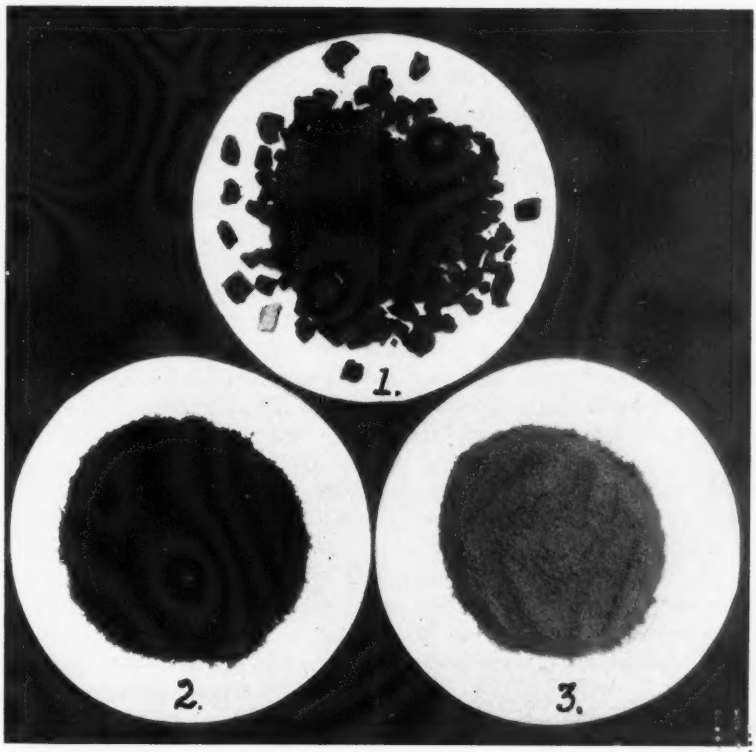
PLATE 1

Charcoal Found on Limestone Plot of Tier 4

Fig. 1. Coarse charcoal taken from the surface of the soil washed free from adhering soil.

Fig. 2. Color of soil of areas 8 and 9 where finely divided charcoal is incorporated with the surface soil.

Fig. 3. Normal soil.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NITRIFICATION IN SOME SOUTH AFRICAN SOILS: PART II

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INTRODUCTION

Since fertilizer dealers and manufacturers in South Africa continue to press the sale of mixed fertilizers for general use in the areas of summer rainfall, despite contrary propaganda and advice from the Union Department of Agriculture, the writer has endeavored to obtain additional data to those already published by him regarding the intensity of nitrification in these soils (2). He has tried to obtain data which might help to illuminate, support or explain that fact so often noted in fertilizer experiments in this area, viz., that nitrogenous manures alone or in mixed fertilizers rarely give any increase in crop yields and when they do it is generally not a profitable one.

This department advises the use of a crop rotation including a legume together with phosphates applied to the grain crops, and the use of lime and potash only when necessary. The latter substances have been profitable rarely and generally only with crops of a limited root system.

On account of the low organic matter content of our soils, the low price of land and the high price of nitrogen, it is bad practice and also bad economics to apply nitrogen costing 1 shilling per pound in mixed fertilizer when it can be obtained more cheaply and in a more suitable form by means of legumes. In the area under discussion optimum soil temperature and rainfall occur together, and thus maximum nitrification can be expected at the time of greatest crop growth. The studies of this and the previous paper clearly indicate that this supposition is correct.

The studies hereafter recorded are in part a continuation and an extension of some of those already published, but some fresh aspects are also dealt with.

I. SEASONAL VARIATION IN NITRATE CONTENT

This is a continuation of the author's previous study (2). Samples for nitrate and moisture determinations were taken as described there. Only two strips of land were kept under observation; one, the cultivated fallow land and another, the uncultivated fallow land which was allowed to revert to grass and weeds during the twenty-one months that the nitrate and moisture was determined. The uncultivated fallow strip does not correspond to the virgin land previously studied, but gave a similar curve in the second summer

by which time it had become more compact, and thus less well aerated and capable of holding water.

A graphic representation of the results will be found in figure 1 which also shows the soil moisture at the time of sampling and the rainfall from December, 1920, to July, 1922. For the soil and air temperatures during this period consult figure 2. As was previously noted, soil moisture and rainfall appear to have a greater influence than temperature on the soil's nitrate content, although the soil temperature was never less than 47.70°F. during the two winters of the duration of this study, and thus was not low enough to stop nitrification, although it may have killed off the enemies of the nitrate bacteria.

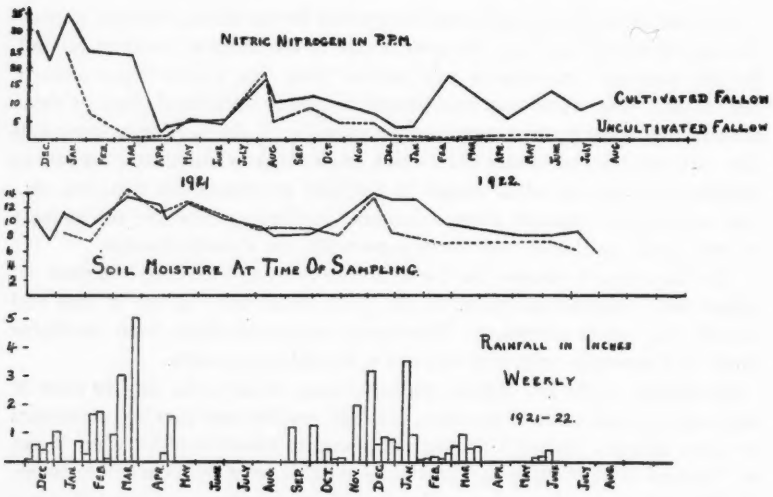

Fig. 1. A Comparison of the Variation in Nitric Nitrogen in Parts per Million in the First Foot of Soil, with the Per Cent of Soil Moisture at the Time of Sampling and the Rainfall During the Same Period

This is indicated by a rise in the nitrate curve in both winters after the commencement of the frosts. It cannot, of course, be attributed solely to the cold as the soil at this time of the year is approaching its minimum moisture content. This low moisture may in itself be sufficient to kill off the protozoa, but the upward tendency of the curve is shortly after the frosts and not after the soil has reached its minimum moisture content.

The influence of high temperature is difficult to gauge since it occurs nearly always around the period of greatest precipitation.

The influence of rainfall is more easily followed. On three occasions there was a distinct rise in the nitrate content following an increase in soil moisture after rain.

The rapid fall in nitrate content in the cultivated fallow land in March 1921, is doubtlessly due to excessive leaching of these salts from the first foot of soil. There was over five inches of rainfall during the last week of that month.

The curve for the uncultivated fallow land nitrate shows a steep fall two and a half months earlier than the cultivated fallow land. This can be ascribed to the rapid growth of grasses which always occurs after the summer rains, and the consequent absorption of the soluble nitrates by their extensive root systems.

Despite a rapidly decreasing temperature there was an increase in nitrate nitrogen both in the cultivated and uncultivated fallow land following the light rains of late April and early May. It appears that more than three inches of rain are required to cause a loss of nitrate from the first foot of this soil by leaching.

After the frosts of June, there was a rapid increase in nitrates in both soils. This reached a maximum after the coldest weather in July 1921. The writer is of the opinion that this rise may have been due to an elimination of competing and predaceous flora by cold. During August there was a drop for which no explanation is offered. This was followed by a slight rise in September due possibly to the increase in soil moisture brought about by an inch of rain a week before the sample was taken. Some of this increase should be ascribed, perhaps to a rise in temperature during this period. From October to January both soils lost in nitrate content. The uncultivated fallow from November on lost more rapidly than the cultivated, due to the absorption of its nitrates by the growing vegetation. The summer rain and luxuriant vegetation compacted this soil so much that its subsequent behavior, due to the loss of its nitrates, poor aeration and dryness, was like that of the virgin soil reported earlier (2). Apparently, the rains in November, December and January, 1922, were too heavy to allow nitrates to accumulate in the first foot of soil. It is only after the rainfall decreased greatly at the end of January and the soil moisture also, that there was a rise in the nitrate content of the cultivated fallow soil. This may have been due to an optimum moisture content for nitrification aided by a capillary rise of nitrate from the lower soil. In spite of a well distributed rainfall of about 2 inches in March, 1922, there was again a fall in the nitrate curve of the cultivated fallow. After the light rains of late May and early June and the killing frosts in the latter month, there was again a decided rise in the nitrate curve. In July there was a fall followed by a rise in August corresponding to a fall in soil moisture and a rise in temperature.

The writer in his previous study of seasonal variation in this soil had noticed the rise in the nitrate curve after the first frosts and thought it suggested partial sterilization due to cold. A colleague who had some unpublished data on a smilar soil type a little further north showed the writer his curves of the nitrate content of the first, second and third foot of that soil, and also gave him his permission to mention them. These data showed an increase in the

nitrate content of the first foot of soil whenever there is a decrease in the second and third foot curves. He suggested interpreting the writer's data by the capillary rise of nitrates. The distinct rise following the frosts, however, appears to be more than a coincidence of capillary. The gravelly nature of the subsoil on this farm also is such as to exclude much of a possibility of a rise of nitrate in this manner. More detailed reasons are given in the next study on the soil wintered in various ways. The results of this study suggest that the writer's previous opinion of the cause of the rise after the frosts is correct.

The 1921–22 summer was one of the driest on record at this station and it shows up clearly in the low nitrate figures. The maximum nitrate content for the year was only 17 p.p.m. whereas in January 1921, there was a crest rising to 35 p.p.m., in January, 1920, 33 p.p.m. and in December, 1919, 49 p.p.m. of nitric nitrogen in the cultivated fallow land.

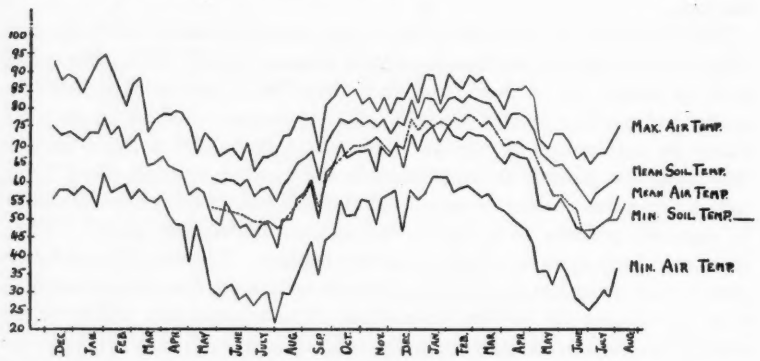

FIG. 2. A COMPARISON OF SOIL AND AIR TEMPERATURE DURING THE PERIOD OF THE DETERMINATION OF THE NITRIC NITROGEN, 1921–1922

The cultivated fallow land, due to the compaction and low moisture content of the soil after the grasses had matured, kept a low nitrate content until June when sampling was discontinued owing to the hardness of the soil. In the previous year the uncultivated fallow land was not so compacted and after the grasses on it had matured its curve clearly followed that of the cultivated fallow.

Soil moisture. There appears to be little difference between the moisture content of the cultivated and uncultivated fallow. During the summer of 1921–22, there was, however, a difference in favor of the cultivated soil. By this time the compaction of the uncultivated soil did not allow it to store so much water, and the grasses also used up much. The greatest difference is 3.2 per cent or about 64 tons per acre foot, enough to produce about 250 pounds more dry matter.

Soil temperature. This was taken every morning at 9 a.m. at the depth of 1 foot by means of an ordinary centigrade thermometer in a brass case which

fitted into a rubber stopper. The stopper was inserted into the mouth of a tube in the ground.

The writer is very pleased to see from Russell and Keen's data (6) that these readings may be taken as representative of the soil temperature at 6 inches below surface. Climatic conditions and radiation are, however, very different at this latitude and altitude from those at Rothamsted, and possibly the minimum may occur earlier. No self recording soil thermometer was available to record this. Russell and Keen also state that the soil temperature at 12 inches, if averaged with the air maximum, gives about the correct soil mean. This average has thus been calculated and plotted in figure 2, along with the air maximum, mean, and minimum and the soil minimum temperatures. The soil minimum temperature is for the most part 1–4°F. higher than the air mean temperature. The soil mean temperature calculated according to Russell and Keen, and over a period of 55 weeks, from the week ending May 24, 1921, to week ending July 31, 1922, was 69.9°F. The mean air average for the same period was 58.8°F. An average difference of 11.1°F. is thus in favor of the soil. The average soil and air minimum temperatures for the same period were 63.4°F. and 43.3°F. respectively, a difference of 20.1°F in favor of the soil population. In some cases the soil was actually 26°F. warmer than the air minimum. Russell and Keene show a difference of 10.8–14.4°F. between their air and soil minimums in favor of the latter.

The drop in soil temperature before winter and the rise after that season gives steep curves. The drop in September, 1921, is probably due to the rain, and in November, December, and March to the same cause. The cooling effect of rain on the soil temperature is more easily seen on the daily temperature sheets.

On an average of thirty-four determinations the, cultivated fallow land was 1.62°F. warmer than the uncultivated.

Conclusions

1. The factors which appear to have influenced the nitrate content of the first foot of soil most strikingly are the leaching effects of heavy rain and the favorable effect of light rain and adequate soil moisture.

2. Aeration also plays an important part, which is apparent in the low nitrate content of the uncultivated fallow soil in the months following the maturity of the grasses, when active growth can no longer be held responsible for the low nitrate content.

3. Temperature appears to play only a small part under our conditions, but it is a difficult factor to judge since it reaches a maximum at the time of maximum rainfall. The cold in early winter appears to stimulate the nitrification process. The soil minimum temperature during two winters was not below 47.7°F. This was not low enough to completely stop nitrification while moisture was adequate.

4. As regards the soil moisture of the cultivated and uncultivated fallow, there is not the difference in favor of the former that agricultural practice would lead one to expect. It is not until the second season when the vegetation is thoroughly established and the soil is compacted that its moisture content is clearly lower.

5. The average minimum of the soil temperature on this station was 20.1°F. higher than air average minimum a few feet away. The soil mean average was 11.1°F. higher than the air mean average, and the soil minimum 1–4°F. higher than the air mean. The living conditions for the soil flora are decidedly more favorable and temperate than the conditions pertaining outside it for other organisms.

6. The amount of soluble nitrogen present during the growing season in the surface foot of the soil studied, would appear to indicate that there is adequate for most crop requirements. It also seems to explain the reason why nitrogenous fertilizers have not given satisfactory returns.

II. NITRIFYING POWER OF SOIL WINTERED IN VARIOUS WAYS

This study was initiated to throw some light on the decided rise in nitrates after the frost as observed in this and in the previous paper (2). The possibility of capillary attraction has been brought up, but it seems strange that this should be so evident only after the frosts have commenced. There may be some capillary attraction but the nature of the lower strata of soil is such as to preclude much possibility of capillary attraction. There is a gravelly subsoil to be found at depths of 18–24 inches. Actual samples were taken down to a depth of 6 feet and the different 1-foot samples superimposed on one another in correct order in a glass tube one inch in diameter. Even under such favorable conditions and from a free water table there was no capillary rise over 6 inches. The third, fourth and fifth feet contained 63, 56 and 44 per cent of coarse gravel respectively. The writer does not wish it to be thought that he does not believe there is any chance of capillary attraction; there may be some from the second foot upwards, but he thinks from the exceedingly well drained subsoil and the low moisture content during winter, that the possibility of a capillary rise of nitrates is remote.

In order to ascertain if the cold weather did not improve the nitrifying capabilities of this soil, representative samples of the cultivated and uncultivated fallow were taken, and each lot divided into two portions. Twelve pounds were placed in glazed porcelain jars which had loosely fitting glazed covers. Two were buried in the field from which the samples were taken, and two were covered and kept in a fume free room in the laboratory from April 25, 1921, to August 22, 1921, when the soils were incubated as shown in table 1 together with field samples from the same places taken on August 17. All six samples were air dried before starting the incubation test. The soils were incubated alone in duplicate, and also with cowpea hay, dried blood, and ammonium sulfate, enough of these being added to give 7 mgm. of nitrifiable nitrogen to every 100 gm. of soil.

Table 1 indicates that:

1. The soil, whether cultivated or uncultivated, had better nitrifying powers after having been exposed to the cold.

2. The soil buried in pots in the field for the most part nitrified better than the soil buried in pots in the laboratory. The differences are, however, not sufficiently great to be very conclusive.

TABLE 1

Nitrification in soil wintered in different ways

NATURE OF THE SOIL AND WINTERING	SOIL ALONE				COWPEA HAY			DRIED BLOOD			AMMONIUM SULFATE			SUMMARY OF ALL NITRIC NITROGEN INCREASES
	Nitric nitrogen at start	After 30 days	Increase in nitric nitrogen	Soil nitrogen nitrified	Total nitric nitrogen	Increase over soil nitric nitrogen	Added nitrogen nitrified	Total nitric nitrogen	Increase over soil nitric nitrogen	Added nitrogen nitrified	Total nitric nitrogen	Increase over soil nitric nitrogen	Added nitrogen nitrified	
	p.p.m.	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*
Cultivated fallow in pot in field	6.5	27.8	21.3	2.0	55.6	27.8	39.7	80.3	52.5	75.0	48.0	20.2	28.8	132.5
Cultivated fallow in pot in laboratory	7.5	31.6	24.1	2.2	45.2	13.6	19.4	73.1	41.5	59.2	43.5	11.9	17.0	91.1
Cultivated fallow field sample, August, 1921	10.9	40.6	29.7	2.8	73.0	32.4	46.2	72.0	31.4	47.7	99.0	58.4	83.4	151.9
Uncultivated fallow in pot in field	3.4	43.6	40.2	3.9	64.7	21.1	30.1	99.2	55.6	79.4	100.2	56.6	80.8	173.5
Uncultivated fallow in pot in laboratory	4.4	28.1	23.7	2.3	49.1	21 0	30.0	72.8	44.7	63.8	47.4	19.3	27.5	108.7
Uncultivated field sample, August, 1921	4.1	26.4	22.3	2.1	58.5	32.1	45.8	82.7	56.3	80.4	81.5	55.1	78.7	165.8

3. The field soils, still more exposed under natural conditions to cold and drying influences, appear to have nitrified somewhat better than the soils in the pots.

4. There appears to be a slight indication that the uncultivated fallow soil nitrified better than the cultivated fallow. It may be that compaction and consequent bad aeration is another factor favoring partial sterilization and subsequent improved nitrification.

5. Two-thirds of the determinations on both cultivated and uncultivated soil showed more nitrates in the soil wintered normally and naturally than in those which were buried in pots to the depth of a foot. The soils in pots did not become as dry as the field soils.

6. The foregoing results in general appear to indicate that the rise in the nitrate curve after the cold weather sets in, may be due to better conditions for the nitrifying bacteria. The data is, however, not conclusive enough to be satisfactory.

A sample of the field soils taken after the coldest winter period, showed no active protozoa. This determination was kindly made by Miss E. Taylor of the University of Witwatersrand.

III. THE NITRIFYING POWER OF VARIOUS DEPTHS OF CULTIVATED AND UNCULTIVATED SOIL

These depth samples were taken and treated as described in part VII of the previous paper, except that the incubation took place in one-pound glass mason jars instead of tins, and in an incubator at 28–30°C. for thirty days instead of in an open room. To the soils were added dried blood, bone dust, ammonium sulfate and ground black jack-hay (*Bidens pilosa*) in amounts so as to add 7 mgm. of nitrifiable nitrogen per 100 gm. of dry soil. This soil type has already been described—a brown sandy soil with an appreciable amount of clay and containing a very gravelly limonite subsoil derived from basic igneous rocks below. The data in table 2 appear to confirm the previous study on this soil and indicate that little nitrification takes place below the first foot. There appear to be indications of some nitrification in every foot of the cultivated fallow, but the increases are so small as to be hardly reliably significant. In this uncultivated fallow there is no nitrification in the fourth foot, a little in the fifth, but none in the sixth foot.

Of the added fertilizers the best nitrified was the ammonium sulfate and the worst the black jack-hay, taking the results through all the 6 feet of both lots of soil.

General nitrification in the first foot of soil, was greater in the uncultivated fallow than in the cultivated fallow. The amount of nitrate reached in thirty days was, however, slightly less than had been actually ascertained from a field sample three weeks after this same land in grass had been ploughed up.

Conclusions

1. This study confirms number 7 of the previous paper and shows that relatively little nitrification occurs in the samples taken below the first foot.

2. The nitrifying power as evidenced by the nitrification of added nitrogenous fertilizers is also low below the first foot samples.

3. The total soil nitrogen decreases regularly from the first to the sixth foot in both soils (see fig. 3).

TABLE 2

Nitrifying power of various depths of soil

TREATMENT OF SOIL	DEPTH OF SOIL	SOIL ALONE				AMMONIUM SULFATE			DRIED BLOOD			BONE DUST			BLACK JACK HAY		
		Nitric nitrogen at start	Nitric nitrogen after 30 days	Increase or decrease	Soil nitrogen nitrified	Total nitric nitrogen	Increase over soil nitrogen alone	Added nitrogen nitrified	Total nitric nitrogen	Increase over soil nitrogen alone	Added nitrogen nitrified	Total nitric nitrogen	Increase over soil nitrogen alone	Added nitrogen nitrified	Total nitric nitrogen	Increase over soil nitrogen alone	Added nitrogen nitrified
	feet	*p.p.m.*	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*per cent*
Cultivated fallow	1	2.1	29.9	27.8	2.3	50.4	20.5	29.2	72.5	42.6	60.8	50.5	20.6	29.4	8.5	*	0.0
	2	3.3	11.7	8.4	0.8	5.8	*	0.0	22.7	11.0	15.7	5.1	*	0.0	4.6	*	0.0
	3	9.4	7.3	*	0.0	11.2	3.9	5.5	3.7	*	0.0	8.0	0.7	1.0	6.2	*	0.0
	4	5.2	5.4	0.2	0.02	4.8	*	0.0	4.9	*	0.0	4.1	*	0.0	6.9	1.5	2.1
	5	1.6	4.3	2.7	0.4	4.4	0.1	0.1	1.6	*	0.0	1.8	*	0.0	2.1	*	0.0
	6	2.6	3.4	0.8	0.2	5.8	2.4	3.4	0.9	*	0.0	1.6	*	0.0	3.3	*	0.0
Uncultivated fallow	1	0.7	36.6	35.8	2.9	78.0	42.2	60.2	13.2	*	0.0	55.3	19.5	29.1	34.6	1.1	1.5
	2	1.1	3.0	1.9	0.2	1.1	*	0.0	2.7	*	0.0	3.9	0.9	1.2	4.1	*	0.0
	3	3.8	2.9	*	0.0	4.3	1.4	2.0	2.7	*	0.0	3.0	0.1	0.1	1.7	*	0.0
	4	4.1	5.1	1.0	0.01	4.6	*	0.0	1.4	*	0.0	0.7	*	0.0	1.8	*	0.0
	5	3.8	2.9	*	0.0	2.8	*	0.0	3.2	0.3	0.4	1.9	*	0.0	1.5	*	0.0
	6	4.1	5.2	1.1	0.3	5.2	†	0.0	3.9	*	0.0	5.0	*	0.0	2.8	*	0.0

*Decrease.
†No change.

IV. A COMPARISON OF THE NITRATE CONTENT OF SOIL BEFORE AND AFTER DRYING IN THE LABORATORY

It has now long been an established fact that if a soil is air-dried in the laboratory and then subjected to nitrification tests it gives better results than the same soil not allowed to dry (1). If a soil is however, not required for nitrifying tests, but merely for a determination of its nitric nitrogen, is the result affected much by allowing it to become air-dried in the laboratory?

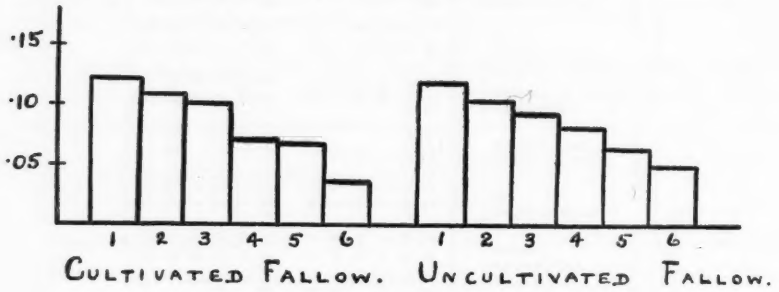

FIG. 3. PER CENT NITROGEN IN FIRST 6 FEET OF SOIL

TABLE 3

Nitrate content before and after drying for twenty-eight days

SOIL DEPTH	CULTIVATED FALLOW, APRIL 19, 1921	CULTIVATED FALLOW, 28 DAYS LATER	CHANGE	UNCULTIVATED FALLOW, APRIL 20, 1921	UNCULTIVATED FALLOW, 28 DAYS LATER	CHANGE
feet	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	2.1	2.3	0.2	0.7	0.6	−0.1
2	3.3	5.2	1.9	1.1	0.6	−0.5
3	9.4	7.4	−2.0	3.8	2.6	−1.2
4	5.2	4.9	−0.3	4.1	3.3	−0.8
5	1.6	2.4	0.8	3.8	3.9	0.1
6	2.6	3.0	0.4	4.1	4.3	0.2
Total.....	24.2	25.2	1.0	17.6	15.3	−2.3
Average...	4.03	4.2	0.17	2.93	2.55	−0.38

To ascertain this, the nitrate content of twelve samples was determined immediately after sampling and again after 28 days of air drying thinly spread on clean brown paper with the following results. All the figures are as nitric nitrogen in parts per million, in table 3.

The average difference is so small as to be well within the experimental error. It would seem then that if it is not convenient to determine the nitric nitrogen when a soil arrives, it can safely be done later if the soil has been spread out thinly to dry.

V. NITRIFICATION IN ACID SOILS

In the writer's previous work it was noted that a number of soils of high lime requirement according to the Veitch Method yet nitrified their own and added nitrogen very efficiently. The writer decided to study three of the soils with the greatest lime requirement in somewhat more detail (3). Throughout this study, the term "acid" means lack of base as indicated by the Veitch lime requirement method. This is a phase of the subject that has received little attention and yet is of great economic importance, especially with low priced land. The soils used are described in table 4.

It is an established fact that liming on acid soil usually increases nitrification, but whereas it may do so profitably on land worth £50 to £250 per acre, it is a different proposition when the land values are 10 shillings to £20, and ground limestone at 11 shillings to 22 shillings 6 pence per short ton.

Another very important factor must be borne in mind when dealing with South African soil problems, and that is their very low phosphate content. Until such deficiency is remedied liming, however cheaply done, can never be

TABLE 4

Three types of acid soils

SOIL NUMBER	SOIL TYPE	WATER HOLDING CAPACITY	VEITCH LIME REQUIREMENT ($CaCO_3$)	TOTAL NITROGEN
		per cent	*pounds*	*per cent*
1	Black peaty clay loam.....	125	3740	0.64
2	Brown sandy loam.....	37	3713	0.05
3	Brown loam.....	64	6473	0.27

profitable investment for the land owner, even though it should greatly stimulate nitrification. Liming, however, even with carbonate of lime greatly improves a soil physically and must sometimes be considered from the economic standpoint. For Russell and Keen (7) show that there was no increase in crops from the heavy chalking of wheat, oats or potatoes, although the land has greatly benefitted physically as shown by lower draw-bar pull, smaller draught per pound, and more miles per hour ploughed.

Object of this investigation

With the above facts in mind it was decided to see whether lime in the form of ground limestone stimulated nitrification in the above mentioned soils, and if it did so profitably.

The soils were incubated as usual in glass jars, after the lime and fertilizers had been added and water at the rate of 70 per cent of the soil's water-holding capacity.

Carbonate of lime, amonium sulfate and superphosphate (acidity calculated as H_2SO_4 was 0.5 per cent) were added in the amounts detailed in

tables 5 to 7. The superphosphate and lime were sprinkled on the top of the 100 gm. of soil in their respective jars and then stirred in.

When both had to be applied to the same soil, first the superphosphate was sprinkled on top then the ground limestone, and both were stirred in together. The ammonium sulfate was in all cases added in solution when the water content was being made up. The figures in tables 5 to 8 are averages.

Soil no. 1 shows very fair nitrifying power which lime has stimulated comparatively little. The limestone at the rate of 1 ton per acre has given most profitable results in this class of treatment. The acid phosphate has stimu-

TABLE 5

Nitrification in acid soil no. 1 (lime requirement 3740 pounds)

TREATMENT PER ACRE	NITRIC NITROGEN	INCREASE OVER SOIL NITRIC NITROGEN	COST OF TREATMENT PER ACRE	VALUES OF INCREASED NITRIC NITROGEN PER ACRE	GAIN OR LOSS PER ACRE
	p.p.m.	*p.p.m.*	*shillings*	*shillings*	*shillings*
Soil alone before incubation	28.1	—			
Soil alone after incubation	116.8	—			
1,000 pounds lime*	90.6	Loss	10	Loss	−10
2,000 pounds lime	124.8	8.0	20	24	4
4,000 pounds lime	128.7	11.9	40	35.7	−4.3
15,000 pounds lime	140.2	23.4	150	70.2	−79.8
1,000 pounds superphosphate	139.7	22.9	55	67.7	12.7
1,000 pounds superphosphate, 1,000 pounds lime	157.1	40.3	65	120.9	55.9
1,333 pounds ammonium sulfate	193.4	76.6	333	229.8	−103.4
1,333 pounds ammonium sulfate, 1,000 pounds lime	237.3	120.7	343	362.1	19.1
1,333 pounds ammonium sulfate, 15,000 pounds lime	237.3	120.5	483	361.5	−121.5
1,333 pounds ammonium sulfate, 8,000 pounds lime	227.3	110.5	413	331.5	−81.5

* In form of ground limestone.

lated nitrification even more than the limestone also more profitably. As phosphate is one of the greatest requirements of this soil there is every likelihood that field results from crop growth would be even more striking. The addition of 1000 pounds of limestone with the superphosphate has stimulated nitrification even more and given the most profitable nitric nitrogen return of the series. The ammonium sulfate has been excellently changed, in fact just shows over a 100 per cent of the added nitrogen nitrified. One thousand pounds of lime added to this has again stimulated nitrificaton profitably, but the heavier applications have not improved it any further. (See table 5)

It appears then that this soil, although showing excellent nitrification, would yet show further profitable increases when 1000 pounds of limestone was added with acid phosphate and ammonium sulfate.

The acid phosphate has stimulated nitrification. This observation concerning phosphates, both rock and acid, has also been made previously by other workers (5) (9).

Nitrification in soil no. 2 is very poor and the actual differences in determinations so small that no satisfactory conclusions can be derived therefrom. Large quantities of limestone have, however, not benefitted nitrification profitably. (See table 6)

TABLE 6

Nitrification in acid soil 2 (lime requirements 3713 pounds)

TREATMENT PER ACRE	NITRIC NITROGEN	INCREASE OVER SOIL NITRIC NITROGEN	COST OF TREATMENT PER ACRE	VALUE OF INCREASED NITRIC NITROGEN PER ACRE	LOSS PER ACRE
	p.p.m.	*p.p.m.*	*shillings*	*shillings*	*shillings*
Soil alone before incubation	4.7	—	—	—	—
Soil alone after incubation	7.7	—	—	—	—
1,000 pounds lime*	9.5	1.8	10	7.2	2.8
2,000 pounds lime	10.4	2.7	20	10.8	9.2
4,000 pounds lime	8.0	0.3	40	1.2	38.8
15,000 pounds lime	14.1	6.4	150	25.6	124.4
1,000 pounds superphosphate	7.9	0.2	55	0.8	54.2
1,000 pounds superphosphate, 1,000 pounds lime	8.7	1.0	65	4.0	61
1,333 pounds ammonium sulfate	4.4	Loss	333	None	333
1,333 pounds ammonium sulfate, 1,000 pounds lime	4.1	Loss	343	None	343
1,333 pounds ammonium sulfate, 15,000 pounds lime	21.4	13.7	483	54.8	428
1,333 pounds ammonium sulfate, 8,000 pounds lime	9.7	2.0	413	8.0	805

* In form of ground limestone.

Nitrification in soil no. 3 is relatively better than that in no. 1 since 2.4 per cent of the total soil nitrogen was nitrified whereas only 1.3 per cent was nitrified in soil 1 and 0.6 per cent in soil 2. Here again limestone has not improved nitrification, but superphosphate seems to have slightly depressed it. The ammonium sulfate has been nitrified to the extent of 35 per cent of the added nitrogen in thirty days. The addition of limestone, however, does not appear to have improved matters. The one result certainly appears unreliable. In the above studies no value has been assigned to the nitrified ammoniacal residue, although this nitrogen is still worth 1 shilling

per pound. The figures show that the limestone in the majority of cases did not help nitrification, and it was for some definite information on this point that the writer was seeking. (See table 7)

Conclusions

1. Even in soils of high lime requirements, nitrification can be adequate for crop production. In two of the soils it is quite up to average of all the soils tested by the writer.

2. The addition of limestone alone has been profitable only in one instance. In the soil that nitrified badly, limestone did not help matters at all.

TABLE 7

Nitrification in acid soil 3 (lime requirement 6473 pounds)

TREATMENT PER ACRE	NITRIC NITROGEN	INCREASE OVER SOIL NITRIC NITROGEN	COST OF TREATMENT PER ACRE	VALUE OF INCREASED NITRIC NITROGEN PER ACRE FOOT	LOSS PER ACRE
	p.p.m.	*p.p.m.*	*shillings*	*shillings*	*shillings*
Soil alone before incubation	8.8	—	—	—	—
Soil alone after incubation	75.2	—	—	—	—
1,000 pounds lime*	77.2	2.0	10	7.0	3
2,000 pounds lime	78.7	3.5	20	12.3	7.7
4,000 pounds lime	81.7	6.5	40	22.8	17.2
15,000 pounds lime	75.5	0.3	150	11.0	139.5
1,000 pounds superphosphate	60.3	Loss	55	None	55
1,000 pounds superphosphate, 1,000 pounds lime	71.1	Loss	65	None	65
1,333 pounds ammonium sulfate	99.2	24.0	333	84	249
1,333 pounds ammonium sulfate, 1,000 pounds lime	63.9	Loss	343	None	343
1,333 pounds ammonium sulfate, 15,000 pounds lime	91.3	16.1	483	56.4	426.6
1,333 pounds ammonium sulfate, 8,000 pounds lime	101.4	26.2	413	91.7	321.3

* In form of ground limestone.

3. In one instance 1000 pounds of limestone has profitably stimulated nitrification where ammonium sulfate was applied, but the heavier dressings of limestone did not improve this process any more.

4. In three instances the addition of 1000 pounds of limestone where 1000 pounds of superphosphate has been applied appears to have stimulated nitrification.

5. In one instance 1000 pounds of superphosphate actually appears to have stimulated nitrification, in one instance not affected it and in one instance apparently depressed it.

6. It would seem, then, that on acid soils, using nitrification as the criterion, applications of limestone would hardly be profitable especially in large amounts. Field trials, however, might show some other benefits from limes. These soils are more acid than the average the writer has tested.

Boussingault and Breal noticed that forest and meadow soils did not contain nitrates and suggest soil acidity as the reason. The writer has not examined forest soils, but has already remarked on the paucity of nitrates in land under natural grass. When this virgin land had been ploughed up, however, there was found three weeks later 30 p.p.m. of nitric nitrogen in soil with a lime requirement of 1000 pounds per acre. Is not the cause as far as the grass lands are concerned, rather that the compaction of the soil brings about poor aeration and that the little nitrate that is produced is readily used up matted numerous grass roots?

VI. NITRIFICATION IN RUSTENBURG TOBACCO SOILS

The soils were collected by the writer in connection with some work on soil type and composition as affecting the nicotine and ash contents and the quality of tobaccos. Eight soils and their corresponding subsoils were sampled to the depth of one and two feet respectively. They comprise three main types, a red loam, changing to a red clay loam, or black clay loam containing about 1.5 per cent of carbonate of lime and a light brown sandy loam. Two of the types, although not containing sufficient carbonate of lime to be detected are alkaline in reaction.

Although the majority of the soils are poor in organic matter and nitrogen, it will be noticed that the percentage of soil notrogen nitrified is fairly satisfactory. All details are given in table 8.

The black clay loams, despite their free lime, did not nitrify their soil nitrogen any better than the red clay loams. The average percentage of soil nitrogen nitrified including soil and subsoil in each class was 3.85 per cent. The brown sandy loams had the poorest organic matter content, and the lowest water-holding capacity, and they also gave the poorest nitrification results. The limed soil 8 from the Rustenberg Experiment Farm had been limed seven years previously, whereas the unlimed soil 7, which had not, gave slightly better nitrification results.

It is also noteworthy that out of eight soils and eight subsoils, with three exceptions, the subsoils produced most nitrates. Approximately 107 pounds are removed by 3500 pounds of tobacco leaf and stalk of nitrogen. On five of the soils, i.e., all excepting the brown sandy loams, nitrification appears to be quite adequate to meet such a demand, but the organic matter and nitrogen content of the soil would have to be maintained and improved, as in no instance is it very good.

Even on the sandy type, enough nitrate nitrogen might be produced during the growing season to meet the demands of the tobacco plant, but it would seem wiser to add an additional amount of nitrogen.

GENERAL CONCLUSIONS

The writer's studies on the nitrifying powers of thirty soils from various parts from the Transvaal as reported in this paper make him retain his former

opinions, that nitrification in these South African soils is not as active as Lipman and his co-workers found it to be on Californian soils and soils from the more humid portions of North America. Whereas, the author had previously found no soil here which had nitrified more than 5.2 per cent of its own nitrogen in 30 days at 28–30°C., he now has found one of granitic origin which nitrified 7 per cent of its own nitrogen in this time, despite its having a

TABLE 8

Nitrification in Rustenburg tobacco soil

SOIL TYPE AND NUMBER	WATER-HOLDING CAPACITY	REACTION OR CALCIUM CARBONATE	ORGANIC MATTER LOST ON IGNITION	NITROGEN	NITRIC NITROGEN AT START	NITRIC NITROGEN AT FINISH	INCREASE ON NITRIC NITROGEN	SOIL NITROGEN NITRIFIED	NITRATE NITROGEN PRODUCED PER ACRE FOOT
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*pounds*
Red Clay Loam:									
Naude 1	41	Alk.	4.19	0.103	1.4	36.2	34.8	3.3	144.8
Naude 1, subsoil	41	Alk.	6.44	0.068	1.3	26.5	25.2	3.7	106.0
Penzhorn 2	35	Alk.	4.45	0.065	2.0	39.7	37.7	5.8	158.8
Penzhorn 2, subsoil	41	Alk.	4.15	0 059	2.0	17.5	15.5	2.6	70.0
Black Clay Loam:									
Combrink 3	60	1.5	5.32	0.081	1.9	35.4	33.5	4.1	141.6
Combrink 3, subsoil	61	1.5	5.74	0.067	1.5	46.7	45.2	6.7	186.8
Combrink 4,	53	0.6	10.62	0.123	2.0	28.4	26.3	2.1	113.6
Combrink 4, subsoil	57	9.0	5.22	0.063	1.6	26.2	24.6	3.9	104.8
Rustenburg Experiment Farm 5	66	1.3	4.98	0.085	2.2	25.2	23.0	2.7	100.8
Rustenburg Experiment Farm 5, subsoil	60	1.45	5.7	0.073	2.1	28.4	26.3	3.6	113.6
Brown Sandy Loam:									
Rustenburg Experiment Farm 6									
Rustenburg Experiment Farm 6, subsoil	37	Neut.	3.82	0.074	1.8	11.4	9.6	1.2	45.6
Rustenburg Experiment Farm 7, unlimed	39	Neut.	4.94	0.056	1.3	11.9	10.6	1.8	47.6
Rustenburg Experiment Farm 7, unlimed	31	Neut.	2.24	0.081	2.7	16.0	13.3	1.6	64.0
Rustenburg Experiment Farm 8	36	Neut.	3.72	0.067	2.0	17.7	15.7	2.3	70.8
limed	32	Sl. Alk.	2.28	0.092	3.3	17.9	14.6	1.5	71.6
Rustenburg Exp. Farm 8, limed subsoil	37	Sl. Alk.	3.41	0.081	3.0	13.3	10.3	1.3	53.2

lime requirement of 2455 pounds per acre and a total lime content of only 0.14 per cent as calcium oxide. It did not, however, nitrify added nitrogenous fertilizers very well. The tables concerning the majority of soils which are more of local than general interest have been recently published elsewhere (4). The data, however, show fairly good nitrification quite adequate for our crop production. The only thing necessary is to maintain the organic matter and

so keep available a cheap supply of organic nitrogen for nitrification. Briefly the chief observations on the particular studies are as follows:

1. Moisture and aeration appear to be factors influencing nitrification under these climatic conditions more than temperature.

2. The seasonal variation study shows a nitrate production which would be adequate for most crops on this soil type and serves to throw light on the reason for the poor results from added nitrogenous fertilizers.

3. The drying of the soil in winter and also the frost appear to improve its nitrifying powers, when conditions again become favorable for nitrification.

4. In this soil type there was very little nitrification in samples taken below the first foot, although traces of activity could be found to the sixth foot in cultivated fallow, but the amounts are too small to be significant.

5. For a nitrate determination only, a soil sample can be allowed to dry out if thinly spread in the laboratory, without the nitrate content being appreciably affected.

6. Nitrification in two of the three acid soils studied was quite good, and not much improved by liming.

7. Nitrification in the Rustenburg tobacco soils was with the exception of two soil types satisfactory. In most cases the subsoils nitrified better than the surface soils.

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ALKALI SOIL INVESTIGATIONS: IV. CHEMICAL AND BIOLOGICAL EFFECTS OF TREATMENTS[1]

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The basis for discussion of the chemical effects in this paper is a second series of experiments conducted primarily with the purpose to study diffusion effects. In some of the cultures, therefore, the sulfur was mixed with the bulk of the soil; in some, only with the surface 4 inches. For a detailed discussion of the chemical effects the third paper (4) of this series should be consulted. The data of the second series only substantiate the results of the first series of experiments. However, the slight modification in the treatments, the use of distilled water, the temperature of incubation (room temperature instead of greenhouse temperature as in the first series of experiments) and the exclusive use of glazed earthenware pots introduced some features not discussed in the third paper, and these will be taken up presently.

Table 1 gives the scheme of the treatments.

Tables 2 to 11, inclusive, give the results. The procedure of obtaining the leachings and extracts was the same as in the first series. It should be noted that the extracts in this series were made on leached cultures (except as shown in table 10), while in the first series they were made on unleached samples.

CHEMICAL EFFECTS

Reaction

Invariably the reaction of the extracts was less alkaline than that of the leachings. This may be attribute to the efficiency of the leaching operations and to the rapid rate of oxidation of the sulfur during the period of drying the leached cultures previous to extraction, which had to be done on air-dried soil. The alkalinity did not disappear in this series as fast as in the first series. The slight variations in procedure, particularly temperature, was responsible for the slower rate. The factor of adding the sulfur to the surface instead of mixing it with the bulk of soil had some slight effect on the reaction of both the leachings and extracts. The acid reaction—pH 6.4—of culture 7 (table 11) is of interest: it may show that the soil is becoming unsaturated, i.e. all the replaceable bases have been forced out. [See note on acidity in (4 p.).]

[1] Paper No. 194 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

Carbonates and bicarbonates

The amount of carbonates and bicarbonates in the extracts follows the tendencies of the reaction, i.e. whenever leaching was facilitated a great part of these substances left the soil. The persistence of the carbonates for a longer period than in the first series may be ascribed to the variation in procedure, as mentioned. The addition of sulfur to the surface soil was not nearly so efficient in decomposing the carbonates as the method of incorporating the

TABLE 1

Treatment of alkali soils, second series

LABORATORY NUMBER	TREATMENT
1	None
2	2000 pounds sulfur applied to surface 4 inches
3	2000 pounds sulfur mixed with bulk of soil
4	4000 pounds sulfur applied to surface 4 inches
5	4000 pounds sulfur mixed with bulk of soil
6	6000 pounds sulfur applied to surface 4 inches
7	6000 pounds sulfur mixed with bulk of soil
8	4000 pounds c.p. alum

TABLE 2

Analyses of leachings after 15 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	AMOUNT LEACHED THROUGH PER POT	C AS CO_3	C AS HCO_3	Cl	Ca	K	S AS SULFATES	REACTION
	cc.	*p.p.m.**	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*pH*
1	91	11.9	386	1639	5.3	388	567	9.4
2	110	23.4	551	2356	3.8	1111	664	9.2
3	87	26.5	546	2650	2.2	673	597	9.4
4	150	25.3	601	2712	2.2	448	344	9.2
5	110	14.6	485	2352	5.3	543	566	9.4
6	87	32.3	556	2700	2.6	413	661	9.5
7	125	15.6	515	2639	3.8	281	651	9.4
8	97	3.6	230	2756	7.3	494	788	9.0

* Parts per million of air-dry soil.

sulfur with the bulk of the soil. It is unquestionable that mixing the sulfur with the bulk of the soil was the better method. It is questionable, however, whether such a practice may be carried out in the field.

The procedure followed in this series of experiments for the extracts gives a better index to the relation between the total carbonates and bicarbonates and those leached than in the first series. The bicarbonates in the leachings fluctuate between 40 and 60 per cent of the total, if the total is taken as the sum of the bicarbonates from the leachings and the extracts on one and the same pot. Attention is called to the fact that such a total does not correspond

TABLE 3

Analyses of leachings after 30 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	AMOUNT LEACHED THROUGH PER POT	C AS CO_3	C AS HCO_3	Cl	Ca	K	Na	S AS SULFATES	REACTION
	cc.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m*	*pH*
1	165	42.0	733	3194	16.2	118	263	693	9.4
2	191	18.7	569	3038	58.8	105	255	839	9.2
3	153	4.7	278	2696	30.7	138	235	824	8.9
4	224	17.0	538	3398	16.2	334	140	953	9.2
5	182	2.1	184	2874	10.2	116	202	1030	8.6
6	212	11.0	459	3286	24.3	137		951	8.8
7	165	1.1	150	2739	24.3	86	241	1020	8.2
8	201	9.3	466	3426	22.6	195	223	988	8.6

TABLE 4

Analysis of extracts of leached cultures after 30 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	C AS CO_3	C AS HCO_3	Cl	Ca	S AS SULFATES	REACTION
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*pH*
2	29.4	314.0	2600	100	1017	8.2
3	29.4	295.0	2600	90	1061	8.4
4	24.5	295.0	1600	100	981	8.2
5	Trace	310.0	2900	100	1247	8.2
6	0.0	260.6	1600	90	1094	8.0
7	0.0	260.6	2200	100	1247	8.0
8	49.0	353.8	1300	80	686	8.6

TABLE 5

Analyses of leachings after 75 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	AMOUNT LEACHED THROUGH PER POT	C AS CO_3	C AS HCO_3	Cl	Ca	Mg	K	Na	S AS SULFATES
	cc.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	105	16.5	422	2089.8	6.8	5.6	184.3	1996	406.7
2	205	7.2	371	3176.8	2.7	15.8	209.2	3165	918.6
3	157	1.6	162	2547.7	6.91	28.4	205.6	2668	852.0
4	252	7.4	389	3169.0	4.70	22.4	206.8	3251	996.0
5	190	1.0	145	2732.7	13.08	44.6	200.9	2940	1023.8
6	272	3.9	295	3215.1	9.27	37.2	189.0	3513	1071.0
7	237	0.9	156	3198.0	15.36	67.0	231.6	3329	1233.0
8	225	10.26	460	3421.7	24.06	11.1	283.6	3370	950.9
2*	240	11.3	520	3215.0	3.9	22.2	170.2	3528	1000.2
3*	245	2.8	243	3352.8	12.46	57.7	186.7	3518	942.3

* Means that after 30 days 2000 pounds more sulfur was added to the surface 4 inches of soil, making a total of 4000 pounds.

to the total obtained when the culture was extracted before leaching; invariably it is higher. The difference must be ascribed to the formation of soluble carbonates during the process of drying from the time of leaching to the time of extraction, usually about 10 days. The alum cultures show a very slight decrease in the total carbonates and bicarbonates. Not all of the carbonates disappeared.

TABLE 6

Analyses of extracts of leached cultures after 75 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	C AS CO_3	C AS HCO_3	Cl	Ca	Mg	K	Na	S AS SULFATES	REACTION
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*pH*
1	49.00	314.7	1700	180.45	82.95	273.45	3477.09	363.7	9.4
2	74.50	270.4	800	180.45	91.69	209.11	2510.38	284.4	9.0
3	19.6	304.9	900	170.42	65.49	199.45	2973.96	306.3	8.6
4	Trace	186.8	800	220.55	89.50	212.32	5190.95†	464.9	8.4
5	00	162.3	748	210.52	80.77	218.76	2857.20	448.5	8.2
6	00	147.5	600	260.65	52.39	199.45	1793.76	470.4	8.2
7	00	98.3	748	360.90	111.33	186.59	1142.51	711.04	8.0
8	39.2	324.5	600	110.27	78.59	199.45	4940.96†	136.7	9.2
2*	Trace	181.93	800	280.70	72.04	218.76	1378.01	582.5	8.4
3*	00	157.3	1100	280.70	69.86	176.94	1755.58	801.30	8.2

* Cultures were leached after 30 days and 2000 pounds of sulfur were incorporated in the surface four inches of soil making a total of 4000 pounds.

† These results cannot be explained; there must have been an error in the determination.

TABLE 7

Analyses of leachings after 140 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	AMOUNT LEACHED THROUGH PER POT	C AS CO_3	C AS HCO_3	Cl	Ca	Mg	K	Na	S AS SULFATES	REACTION
	cc.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*pH*
1	150	26.4	498	3073	5.5	2.9	119.171	2863.69	551	9.4
2	257	3.0	240	3391	52.8	20.5	108.509	3708.60	845	8.5
3	244	1.2	162	3293	103.9	37.9	103.091	3357.08	1028	8.3
4	237	1.6	217	3165	71.4	29.9	112.126	3649.95	974	8.6
5	255	0.0	143	3033	114.7	57.2	105.720	3300.19	1043	8.2
6	260	0.7	204	3212	95.0	47.7	105.332	3671.65	1102	8.4
7	237	0.0	95	2896	103.5	77.0	140.424	3340.95	964	7.8
8	225	7.8	373	3589	18.7	6.2	112.363	3642.85	873	9.2
2*	245	0.7	180	3316	66.7	41.3	76.013	3746.44	1024	8.2
3*	233	0.0	71	2397	77.6	45.7			941	8.0
2†	255	1.6	211	3232	56.3	22.9	94.041		991	8.6
3†	250	1.2	155	3008	99.6	36.3			964	8.4

* Means that 2000 pounds of sulfur was added after 30 days without leaching making a total of 4000 pounds of sulfur. Peat at the rate of 5 tons per acre was also added after 30 days. These were leached only after 140 days.

† Peat was added to these cultures after 30 days.

TABLE 8

Analyses of extracts of leached cultures after 140 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	C AS CO_3	C AS HCO_3	Cl	Ca	Mg	Fe	K	Na	S AS SULFATES	REACTION
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*pH*
1	53.9	329.4	1300	120.3	93.8	670.8	318.4	1715.8	382.8	9.0
2	4.9	265.5	650	154.3	89.5	559.0	276.6	1008.4	328.1	8.2
3	4.9	265.5	650	160.4	82.9	614.9	260.5	1345.2	339.1	8.2
4	0.0	177.0	700	210.6	93.8	391.3	225.1	1429.9	508.6	8.0
5	0.0	118.0	850	250.5	74.2	279.5	225.1	1689.5	563.3	7.8
6	0.0	132.7	750	270.5	78.5	335.4	221.9	1738.0	607.1	7.8
7	0.0	78.6	750	681.0	69.8	167.7	270.2	1435.8	1080.2	7.4
8	29.4	341.7	650	130.5	137.5	614.9	295.9	1166.0	185.9	8.8

TABLE 9

Analyses of leachings after 190 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	AMOUNT LEACHED THROUGH PER POT	C AS CO_3	C AS HCO_3	Cl	Ca	Mg	K	Na	S AS SULFATES	REACTION
	cc.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*pH*
1	60†	12.1	249	1681	2.6	3.8	79.4	1455	337.6	9.4
2	252	0.4	240	3252	66.3	28.3	113.5	3623	1043.0	8.2
3	225	....	76	3073	90.2	36.0	121.9	3282	1022.0	8.2
4	215	....	137	3073	73.0	51.5	105.0	3425	1085.0	8.2
5	270	....	132	3362	95.6	73.6	105.0	3919	1311.0	8.0
6	250	....	125	2990	86.6	65.9	89.1	3367	1082.0	8.0
7	220	....	78	3141	98.1		102.1	3479	1218.0	7.2
8	125†	0.7	211	2962	17.2	15.6	113.5	3037	768.7	8.8
2*	220	....	91	331	25.2		22.7	598	307.4	8.2
3*	215	....	48	331	59.2		56.7	625	358.7	7.6

* These were leached after 140 days, at which time an addition of 2000 pounds of sulfur and peat at the rate of 5 tons per acre were added.

† These became water logged after 48 hours. No. 1, therefore, received only 285 cc.; and No. 8, 315 cc. All others received 400 cc. and leached through in 20–24 hours.

TABLE 10

Analyses of extracts of unleached cultures after 190 days' incubation; 2d series

LABORATORY NUMBER OF TREATMENT	C AS CO_3	C AS HCO_3	Cl	Mg	K	Na	S AS SULFATES
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	31.36	420.89	4200	207.39	180.152	5215.087	820.44
3	0.0	153.10	4100	130.98	102.944	5194.33	1490.47
4	0.0	125.87	4100	98.235	93.293	4965.53	1679.17
6	0.0	116.04	3900	141.89	70.774	4982.42	1845.99
7	0.0	66.87	4200	148.44	83.642	5130.13	2392.95
8	7.84	277.32	4000	87.32	119.029	4474.14	1080.25

Chlorides

The cultures of the 30-day incubation period show an abnormally high chlorine content. It cannot be explained except on the basis of some error in the analyses detected too late to be checked up. The other cultures show that there are about 4000 parts per million of chlorine in this particular soil. These experiments substantiate the conclusions reached in the third paper of this series (4) in regard to the chlorine in alkali soils: it is easily leached out.

Calcium

Not much more may be said about the calcium data in this series than what has been said about it the first series. The increase in the calcium of the sulfur-treated cultures undoubtedly points to the presence of large amounts of this

TABLE 11

*Analyses of second leachings after 335 days of cultures leached for the first time after 190 days' incubation; 2d series**

LABORATORY NUMBER OF TREATMENT	C AS CO_3	C AS HCO_3	Cl	Ca	Mg	K	Na	S AS SULFATES	REACTION
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*pH*
2	1.84	24.6	383.0	25.3	16.0	27.0	632.3	326.8	8.8
3	1.46	20.5	617.2	28.9	11.6	34.8	948.4	348.4	8.6
4	0.97	12.8	507.0	76.0	61.3	36.9	824.0	470.6	8.4
5	0.0	6.12	388.5	88.4	29.5	33.3	658.1	376.2	8.0
6	Trace	12.7	647.5	182.7	142.5	70.2	1233.3	786.2	8.2
7	0.0	2.00	542.8	92.5	64.8	44.0	832.9	559.5	6.4
2†	0.0	5.58	330.6	93.1	47.5	31.9	644.53	460.6	8.0

* No leachings could be obtained from the untreated cultures. Not a drop leached through even after being in contact with the water for 10 days.

† This culture was treated originally with 2000 pounds of sulfur. After 140 days it was leached and to it 2000 pounds more sulfur was added. Leached again after 335 days.

cation in the zeolitic portion of this soil. The data on the calcium in table 11 where analyses of the second leachings are reported show that more calcium has come out from the zeolites. One other point has to be kept in mind in interpreting the calcium figures. On account of the preponderance of the sulfate ion a great deal of the calcium combines with it, forming gypsum. The extracts, therefore, do not show the true amount of calcium replaced. An analysis of the zeolitic cations capable of replacement will give the true value. This is being investigated and indications are on hand proving the truth of the assumption.

Magnesium

There is not much soluble magnesium in this particular soil, neither is there any zeolitic magnesium capable of replacement. From 15 to 30 per cent of the total is leached out.

Sodium

Outside of the few discrepancies indicated in the tables, the data on the sodium shows that the soil under investigation has not much zeolitic sodium to be replaced. There is some increase in the sodium content of the treated cultures. If the sodium had been in preponderance, then the calcium with its higher coefficient of absorption would not have been replaced last. The data of the second series of experiments confirm the postulate made in the third paper (4), namely, that this soil is not a purely sodium alkali soil. The presence of large amounts of sodium in solution points to the genesis of this alkali soil, namely that it is either in the process of desalinizing or *more likely in the process of formation.* Table 11 gives the data on cultures which have been leached once after 190 days and then again after 335 days. If there were zeolitic sodium it would have shown up in these second leachings. There are, however, only slight indications of this nature.

Potassium

The conclusions reached in the first series of experiments, notwithstanding the errors due to the pots, have been fully substantiated by this second series.

Sulfur

The extracts and the leachings do not show the true amount of the sulfur oxidized, since appreciable amounts of the sulfates combine with the calcium replaced, forming gypsum. That in some cases all of the sulfur has been oxidized may be inferred from the data on the reaction and carbonates in table 11. If sulfur were there the reaction could not have gone back to more alkalinity and no soluble carbonates could exist. The figures in table 11 are instructive in another way; they show that only 6000 pounds of sulfur is capable of bringing the reaction towards slight acidity and that 4000 pounds of sulfur is sufficient to keep down the soluble carbonates. These facts shall corroborate the studies on the zeolitic cations capable of replacement and a correlation of the two shall give a pretty close answer to the question of how much sulfur is necessary to apply to this particular soil to keep a favorable reaction for plant growth and at the same time keep away the soluble carbonates.

GENERAL DISCUSSION ON DIFFERENT AMELIORATING AGENTS

The studies on the California alkali soil as revealed in the analytical data of the two series of experiments presented in the previous papers and in this paper suggest some specific ideas on the subject.

The treatment of any black alkali soil must be guided by the principles mentioned (3, p. 18). To accomplish the favorable effects as a result of the application of these principles the proper agent in reclaiming the black alkali soils is of prime importance. The three agents discussed are gypsum, alum, and sulfur. A summary of their merits as ameliorating agents may not be out of place.

Gypsum

The initial step in treating black alkali soils as outlined by the authors is to coagulate the colloids. This brings about a marked improvement in the physical condition of the soil, makes it pervious to water and thus allows efficient leaching. Because they did not consider the factor of colloids, the earlier investigators and even some recent ones have recommended gypsum under all conditions. From the discussion presented in this series of papers by the authors, it should be clear that gypsum on account of its slow solubility cannot be reckoned as an efficient coagulant.

The second step in any rational method of treating black alkali soils is the replacing of the zeolitic sodium or any other cation. Gypsum allows only few calcium ions to be active in the replacement process because of its slight solubility. The low concentration of calcium ions is rapidly overwhelmed by the increasing concentration of the sodium ions; under such a condition no more calcium may enter the zeolitic portion even though it has a higher coefficient of absorption for reasons pointed out (3, 4). If, upon leaching, the sodium compounds come back from the lower horizons to the surface horizons, then the newly accumulated excess of sodium in the soil solution will replace the few calcium ions from the gypsum which entered the zeolitic portion of the soil; the calcium will then combine with whatever anion the sodium was in combination as it came from the lower horizons. In the case of sodium chloride, the toxic calcium chloride is formed. Otherwise gypsum is formed again and equilibrium is reached in the system. At this point, if carbonates are present, there is the possibility of forming soda.

The cycle thus described fully supports the theory of Gedroiz on the process of black alkali soil formation. The only exception where the theory of Dominicis, which does not require the presence of carbonates (3, p. 17), may be upheld, is when some hydrogen ions from water enter in the replacement process leaving behind the hydroxyl ions; these unite with the Na ions forming NaOH, which absorbs CO_2 and forms soda.

The third step in this process is to create a favorable reaction for plant growth. Gypsum may not be relied upon to reduce the alkalinity, since the products of the reaction are not of an acid nature; inasmuch as the soluble carbonates are converted into insoluble carbonates, some reduction of alkalinity will take place. We must agree, however, that the driving force of the reaction towards the insoluble carbonates is greater than in the reverse direction, something which is not at all always probable. The work of Kelley and Thomas (5) substantiate the above conjectures.

Alum

The use of alum to accomplish the first step mentioned has been suggested by Scofield [see reference in earlier paper (3, p. 30)]. An application of alum brings about a favorable condition for leaching since the trivalent aluminum is an excellent colloid coagulant.

In reference to the replacement capacity of alum it is interesting to note that only the potassium cation seems to be able to serve as a replacing agent; the aluminum apparently does not take part in this reaction. For this reason the usefulness of alum as an ameliorating agent ceases with its coagulation reactions. There may be conditions, however, which will justify the use of alum (the practicability from standpoint of cost is not considered here) and these may be as follows:

1. In an alkali soil not saturated with sodium in its zeolitic portion, but in which the sodium carbonate is beginning to show. Cases of that sort may be found in black alkali soil region in process of formation, *the probable condition of the California soil under investigation.*
2. In such a soil leaching alone could accomplish the task of removing the excessive soluble salts and the alum treatment would be sufficient if means could be provided to prevent the sodium from the lower horizons from coming to the surface. The maintaining of such a condition is possible by means of a good drainage system, if such may be constructed conveniently.

As far as the third step (reaction) is concerned, the alum as shown by the studies in these papers can reduce the alkalinity only inasmuch as the alum carries free acid with it. The amount of soluble carbonates, as may be seen from the tables, has changed but little. Thus the use of alum as a remedy to change the inherent characters of black alkali soil cannot be advised, and its merits are limited.

Sulfur

In the form of commercial flour, sulfur does not react to any extent and therefore may be disregarded as a coagulant of colloids. Its use as an effective coagulating agent is based on the biological oxidation with the formation of sulfuric acid as an end product. After fourteen days, as shown previously (4), the colloids have been coagulated. It is interesting to note that the behavior of sulfuric acid in respect to coagulating power differs in the alkali soil extracts and alkali soil itself; in the soil its coagulating power is quite marked, while in the extracts it is insignificant. The effectiveness in the soil may be attributed to compounds other than the sulfuric acid itself; these compounds in combination with the sulfuric acid are probably responsible for the high coagulating powers.

In regard to the replacing power of the sulfur oxidation products not much may be added in the summary. The hydrogen ions tend towards the formation of an acid soil replacing all the cations in the zeolites with hydrogen. In black alkali soils with sodium saturated zeolites the surest and quickest method would be the replacement by hydrogen. Any sodium from the compounds, which are bound to come from the lower horizons or from the irrigation waters, is prevented from entering the zeolites on account of the high coefficient of adsorption of the hydrogen ions. Furthermore, it would be advantageous to use lime after the sodium compounds have been replaced and the soil has been leached. The calcium ions would enter the zeolitic portion forming calcium

zeolites, and as long as an excess of sodium could be prevented from invading the soil again such a procedure would bring the soil to an ideal physical and chemical condition.

Sulfur oxidation prevents the formation of any soluble carbonates; the hydrogen-ion concentration of the extract may be kept at a level which should not be injurious for plant growth. If the soil is a calcium-sodium alkali then the products of sulfur oxidation replace the calcium which upon entering the soil solution forms gypsum; eventually the calcium ion would tend to go back into the zeolite. In a calcium alkali soil the amount of sulfur necessary will be guided by the leaching capacity of the soil. It is understood that steps are to be taken to prevent other alkali forming substances from rising to the surface. As a rule, however, sodium accompanies the calcium and under such conditions it is important to have an excess of sulfur to prevent the formation of soda.

PRACTICAL CONCLUSIONS

The soil under investigation has some soda and also some sodium in the zeolitic portion. For the best results the following reasoning may serve as a guide in deciding upon the time of leaching. When the colloids have been coagulated, the carbonates begin to disappear; some go off as CO_2, some are converted into bicarbonates, some CO_2 is utilized by the autotrophic microbial flora. The reactions with the carbonates probably take place first, since they are solution reactions. They are followed by replacement reactions. From the nature of the cations it is expected that sodium shall come out first followed by calcium. In making frequent determinations, the point at which all or most of the sodium has been replaced may be detected; only then leaching should be resorted to. The sulfur oxidation following leaching will supply the hydrogen ions for the replacement of the calcium, which as mentioned forms gypsum. After all the sulfur has been oxidized and the supply of hydrogen ions has been exhausted the reverse reactions will take place as shown in the following equations:

$$CaAl_2SixOy \cdot nH_2O + H_2SO_4 = H_2Al_2SixOy \cdot nH_2O + CaSO_4 \cdot 2H_2O$$
$$H_2Al_2SixOy \cdot nH_2O + CaSO_4 \cdot 2H_2O = CaAl_2SixOY \cdot nH_2O + H_2SO_4$$

No definite amount of sulfur may be recommended; a quantitative determination of the replaceable cations, as indicated previously, will tell the story. It seems as if 4000 to 6000 pounds of sulfur was sufficient under the conditions of these experiments.

The combination effects of sulfur and alum in ameliorating the physical condition of the soil bring forth the possibility of the use of these two ameliorating agents in treating alkali soils. The advantage would be that the alum would immediately coagulate the colloids and thus the hydrogen ions from the sulfuric acid would be utilized for the replacement of the sodium. Such a procedure is apt to shorten the period of reclamation. Further studies in this

direction would probably show more concrete possibilities of these two ameliorating agents.

The use of organic substances such as peat or large amounts of manure are effective inasmuch as they serve as buffers and constituents to be reacted upon by the soda. They have not, however, any cations capable of replacing the noxious cations of the zeolitic portion of the soil. Their effectiveness is, therefore, only temporary. One thing, however, that these organic substances introduce, is some plant food which a number of alkali soils lack.

Fertilizer application

The soil under investigation, as pointed out, is very poor in nitrogen. It has not very much of phosphates either. These soils after treatment would respond to fertilizers. The most logical inorganic nitrogen source would be ammonium sulfate. It is possible that the NH_4 ions become fixed in the zeolitic portion only to be replaced later by the calcium ions of the gypsum. Whether nitrification of the ammonium is possible while it is in an adsorbed condition in the zeolitic portion is of course problematic; it probably would be nitrified as it is replaced and from this point of view it would be of an advantage since none would be leached out. Ammonia determinations at the various periods of incubation would tell the story. This subject has not been investigated.

From the nature of the alkali soils it would be logical to use calcium nitrate, having the calcium as one ion that enters the zeolitic portion. After leaching, an application of lime would be advantageous augmenting the store of calcium for replacement. Whenever alum alone may accomplish the ameliorating effects, an application of gypsum would be the better source of calcium.

BIOLOGICAL EFFECTS

The study of any soil problem is incomplete, unless all of the phases of soil fertility are looked into. It has long been recognized that the biological structure of the soil plays an important rôle in soil processes and in the reactions accompanying them. No definite function or group of functions have been as yet found to serve as a guide to get a clear idea of the existing relationships between the biological structure of the soil and soil fertility. The increase in numbers of bacteria, one of the earliest phases investigated and recognized, has often served as an excellent indication of the probable condition of the soil.

It has been suggested by Barnes and Ali (1) that the salts present in alkali soil do not exert any toxic effect on the plant. The danger point in alkali soil is reached when the osmotic pressure of the saline solution becomes equal to that of the cell sap. This happens irrespective of the nature of the salt provided it possesses no toxic properties. Such salts as sulfates and chlorides of sodium or calcium exhibit no toxic properties to plant protoplasm. Even

Na_2CO_3 cannot be said to be toxic though it is known that it shows evidence of caustic action on the stems of the plants. Whether the caustic effect is produced on dead or living tissue is not known. They conclude therefore that CO_2 formation, nitrification and nitrogen fixation might be used to measure the crop producing power of alkali soils. These views are interesting and deserve more attention; their conclusions, however, seem to be of little value, since the question of indications for the productivity in alkali soils is not at all troublesome.

The condition of the black alkali soil investigated is such that no green plants are capable of carrying on their active life processes. Still the bacteria exist and undoubtedly function.

Bacterial numbers

Table 12 gives the number of bacteria in alkali soils at the various incubation periods with the different treatments under leached and unleached conditions.

It is of interest to note that there is practically no increase in bacterial numbers after 60 days of incubation. The data in general do not seem to substantiate the supposition of Barnes and Ali, since even without leaching an increase in bacterial numbers after 95 days incubation with the high sulfur applications may be noted. It is very probable that if toxic effects are responsible for the low count of bacteria then the increase of calcium due to the replacement process is by the force of its antagonism responsible for the increase in number; the decrease in soluble carbonates will also tend to work in that direction. The decrease in numbers after 140 days may be explained on the basis of increased concentration of salts due to the sulfur oxidation. Vegetation experiments showed somewhat similar results as pointed out presently. It is worth while to record that in no case has the alum treatment caused an appreciable increase in the bacterial numbers; neither has the peat. This again points to the low efficiency of these substances as ameliorating agents of alkali soil conditions.

Nitrification

Alkali soil cultures variously treated and leached at the various incubation periods were air-dried, 100-gm. portions were placed in tumblers and to each one 25 mgm. of nitrogen in the form of ammonium sulfate or dried blood was added. Table 13 gives the data on the nitrate nitrogen found after 46 days of incubation.

The results are conflicting and no conclusions may be drawn. A great deal of the inconsistent results must be ascribed to the method used in determining nitrate nitrogen. It is known that chlorides interfere with the determination of nitrates and they have to be precipitated with silver sulfate. Even then it was found that in many cases some nitrates could not be recovered and in some cases the results were too high. The data on the unleached cultures give an idea of the amount of nitrates present in this alkali soil.

TABLE 12

Influence of treatmenit on bacterial numbers in alkali soil

LABORATORY NUMBER OF TREATMENT	TREATMENT	BACTERIA PER GRAM OF SOIL AFTER				
		14 days*	60 days†	95 days†	108 days‡	140 days†
		hundred thousands	*hundred thousands*	*hundred thousands*	*hundred thousands*	*hundred thousands*
1	None	5.94	4.92	5.44	4.41	4.92
2	4000 pounds sulfur	6.40	4.40	4.85	9.92	5.61
3	4000 pounds sulfur + 5 tons peat	7.41	4.96	5.81	17.07	5.78
4	6000 pounds sulfur	4.45	5.97	13.20	32.05	6.33
5	6000 pounds sulfur + 5 tons peat	6.40	5.80	23.00	69.33	12.52
6	2000 pounds sulfur	6.07	4.73	4.55	6.9	5.08
7	2000 pounds sulfur + 5 tons peat	4.16	4.71	4.96	6.2	5.41
8	4000 pounds c.p. alum + 5 tons peat	4.63	4.91	5.41	4.28	5.63
9	4000 pounds c.p. alum + 2000 pounds sulfur	5.96	4.04	4.36	5.4	5.60
11	5 tons peat		5.80	4.1	6.1	5.36

* Bacterial numbers determined on soils after leaching.

† Unleached.

‡ These were leached twice; first after 14 days.

TABLE 13

Nitrate nitrogen after 46 days' incubation in alkali soils variously treated for various incubation periods

LABORATORY NUMBER OF TREATMENT	INCUBATION PERIOD OF TREATED SOILS								
	Dried blood					$(NH_4)_2 SO_4$			
	15 days	30 days	75 days	140 days	190 days*	15 days	30 days	75 days	140 days
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	46.2		21.95	23.1	160.0	62.4		39.2	31.2
2	66.6	49.0	39.2	25.5		54.0	19.6	14.7	19.6
3	62.7	27.0	23.1	32.3	224.0	54.0	23.1	21.5	27.0
4	69.8	29.4	23.1	10.2	192.0	62.4	12.7	14.6	86.2
5	66.6	15.7	86.2	23.1		54.0	8.8	39.2	13.5
6	74.5	24.5	58.8	27.4	208.0	54.0	8.8	21.6	10.8
7	51.0	11.7	21.5	23.1	160.0	54.0	4.6	7.8	13.5
8	53.0	4.9	35.3	39.2	192.0	62.4	10.8	14.6	25.5

* Nitrogen as nitrates on unleached cultures.

Vegetation experiments

The soil under investigation is bare of vegetation. Whether toxicity, reaction or osmotic concentration is responsible for the practical sterility of the soil as far as green plants is concerned matters little at the present moment;

it is probable that a combination of these three factors is responsible for the results. Wherever thorough leaching was possible vegetation could be established. The alum treatment was efficient therefore in the beginning. However, if the alum treatment was not followed immediately with leaching there was no hope of obtaining a stand of any kind of a crop. This was evident from the first series of experiments. In the second series a more accurate account may be given since in this series some of the errors, like absorption by walls of pots, were eliminated. All the records as given in table 14 and plate 1 are on leached soils, except that of 190 days.

It will be noted from table 14 that the barley made growth even on the untreated cultures (no. 1) after 15 and 30 days. The reason for such a behavior is that at this period the soils were not as compact and allowed leaching. However, in the later periods of incubation the soils became compacted pre-

TABLE 14

*Record of barley crop grown in pots of variously treated alkali soils after various incubation periods**

LABORATORY NUMBER OF TREATMENT	DRY WEIGHT OF CROP			
	15 days	30 days	75 days	190 days†
	gm.	*gm.*	*gm.*	*gm.*
1	0.136	0.160	0.000	0.000
2	0.413	0.525	0.507	0.155
3	0.283	0.394	0.462	0.124
4	0.299	0.344	0.547	0.140
5	0.314	0.456	0.464	0.151
6	0.365	0.251	0.539	0.099
7	0.129	0.420	0.473	0.089
8	0.058	0.138	0.000	0.000

* The barley was attacked by mildew and the crop had to be harvested before maturity.

† This lot was planted before leaching. The same pots were leached and planted to millet. Plate 1 gives the results.

venting the leaching of the untreated cultures. Then the noxious features of the alkali soils became apparent: the barley barely germinated, but made no growth. The figures on the 190 day cultures are interesting. They show that even without leaching some growth may be obtained on treated soil although not as goos as when leached. These figures bear out the data on bacterial numbers. It is undoubtedly true that the neutralization of the soda and the bringing into solution of calcium ions which antagonize other toxic elements, had their influence. Still it is apparent that the concentration of the salts prevented better growth; especially is this evident from cultures 6 and 7, the highest sulfur application.

After the barley was harvested millet was planted. Plate 1 is a photograph of the 190-day culture where barley was grown before leaching, leached after that and planted to millet. The 190-day set was selected as typical and the photograph is self-explanatory.

CONCLUSION

This series of papers reporting the work with alkali soil should be looked upon as an attempt to bring before the investigators in this important field of research a clear picture of the problem as revealed by the most recent theories on the subject, especially that of Gedroiz. The data presented in the light of these theories seem to give a theoretical working basis; the practical aspect of the problem will undoubtedly force a modification of the steps involved; the principles outlined, however, seem to be sound.

METHODS OF ANALYSIS

Whenever possible, the official methods were used and there is no necessity in pointing out the details. The extracts were prepared by mixing 50 gm. of soil with 500 cc. of distilled water. The mixture was shaken every ten minutes during the day, left over night, decanted, centrifuged for 1.5 hours and then filtered through plaited filter. The first 100 cc. were discarded, allowing the filter to saturate with the solution.

The hydrogen-ion concentration of the leachings or extracts was determined colorimetrically by the Clark and Lubs method as outlined in Clark (2). Wherever the colors failed to give a good reading the potentiometer was used.

In making bacterial counts, 8 to 10 plates were used for each culture with a synthetic medium consisting of the regular mineral salts with 1 per cent dextrose as the source of carbon and egg-albumin .05 per cent, as the source of nitrogen. The reaction of the medium was adjusted to pH 6.8–7.0.

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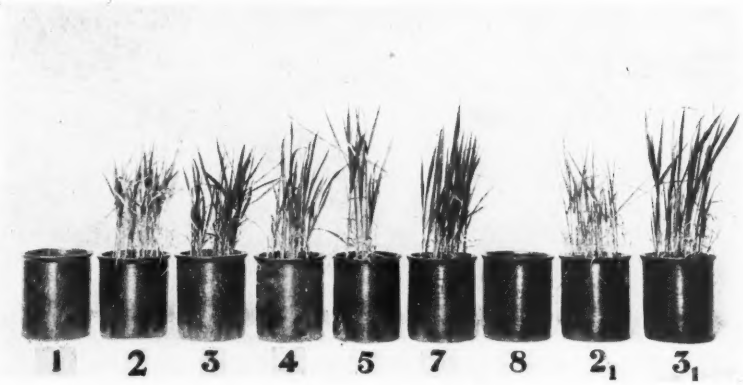
PLATE 1

PHOTOGRAPH SHOWING CROP OF MILLET FOLLOWING BARLEY ON LEACHED SOILS

Numbers indicate treatment as outlined in table 1. Pots 2, and 3, have been leached after 140 days and 2000 pounds more sulfur added to them.


1
2
3
4
5
7
8
2₁
3₁